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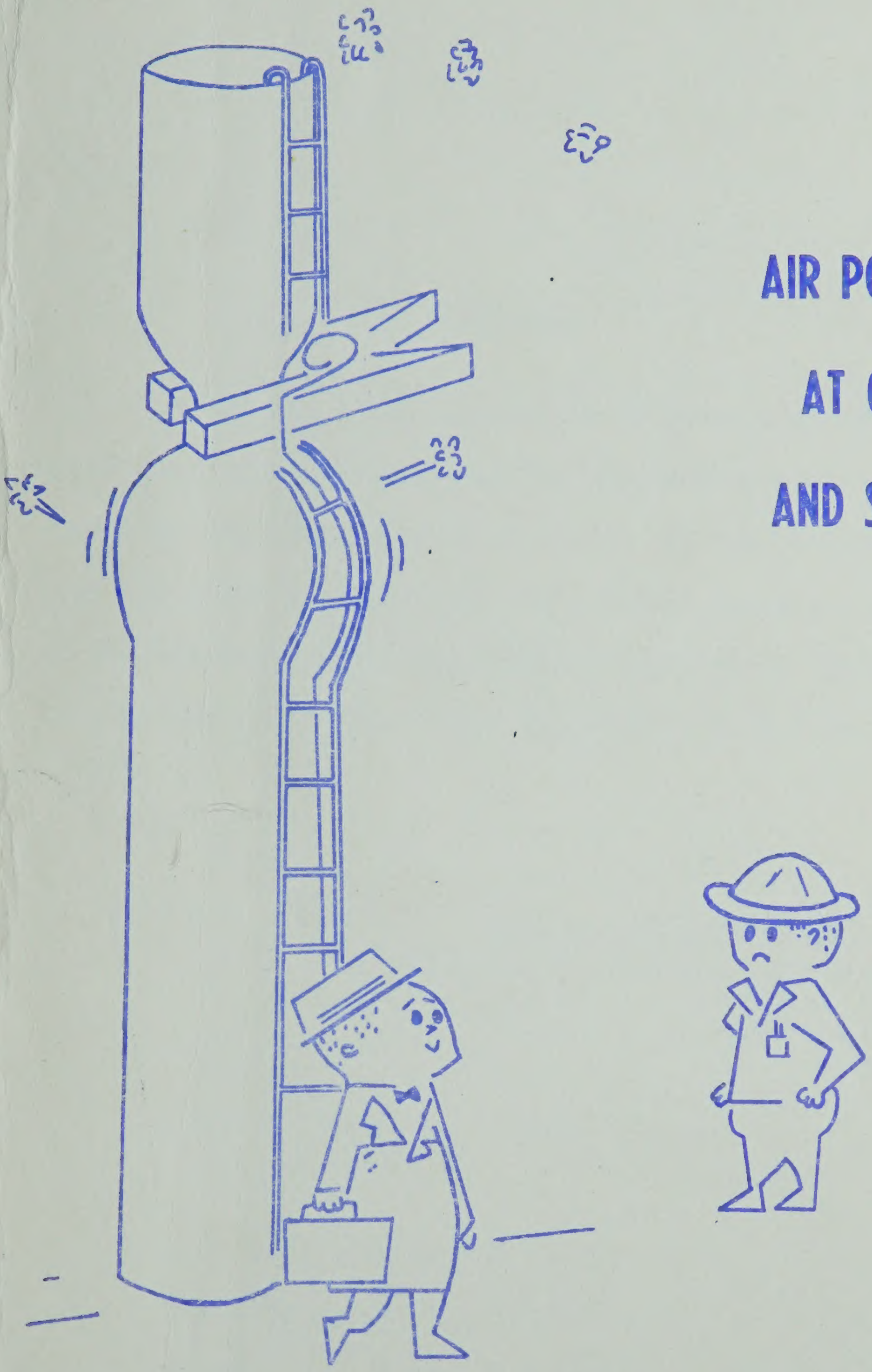

AIR POLLUTION CONTROL AT GAS PROCESSING AND SULFUR RECOVERY PLANTS

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DEPARTMENT OF HEALTH
Division of Environmental Health Services
February, 1969

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FOREWORD

Air Pollution knows no boundaries and as such atmospheric pollutants are readily transportable and dispersed by the wayward action of winds. No one group has the sole right to contaminate our greatest resource, Air, to the detriment of his surrounding neighbors and because of this there is an obligation for control at the source.

Sergius L. Dobko, P. Eng.,
Head, Air Pollution Control Section.

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AIR POLLUTION IN GENERAL

INTRODUCTION

The air that we breathe is one of the most important resources we have. Man is directly dependent upon it for breathing and indirectly depends on it for his economy and well-being.

Atmospheric pollution is not a new phenomenon and it undoubtedly originated when man first lit a fire. A bush or forest fire must have occurred in an area of restricted ventilation resulting in contamination of the air by smoke. Air pollution was recognized as a problem during Roman times and by the 18th century it was prevalent in most major cities of Europe and North America.

When we think of the air pollution problem, we normally associate its source with some activity of man. Man, however, is not solely responsible for air pollution. For example, the haze normally seen in the countryside is associated with plant life. Wind-borne dusts, salt spray and pollens are also natural contaminants of the atmosphere. Practically all air is contaminated to some extent and air pollution basically is caused by introduction of foreign substances into the atmosphere. If the concentration of these contaminants interferes with the well-being of people and their economies, a pollution problem may arise. One of the difficulties in combating air pollution is the variety of its effects on people. A housewife may have her furniture and clothing soiled, a farmer is interested in the effect it may have on his crops, a tourist may be inconvenienced by a reduction in visibility or an obnoxious odor.

Air pollution may be caused by many substances coming from a variety of sources. It can come from automobile exhaust pipes, carburetor, crankcases, and home furnaces. Waste disposal operations such as incinerators, open burning of dumps, the burning of leaves and wastes of construction and demolition are significant sources of pollution. Large volumes of pollutants are also emitted from oil refineries, power plants, steel mills, pulp and paper factories and almost every other kind of industry.

Normally, natural atmospheric conditions absorb these pollutants. Thorough mixing brings about a dilution of the contaminants; rain, snow, and dew helps remove the dust, smoke, and gaseous pollutants. Absorption of gases by vegetation, soil, and water are other natural air cleaning processes. If this happens as fast as pollutants are released, then the consequences are negligible. However, peculiar weather conditions may interfere with this normal phenomena and a pollution problem may arise due to stagnant air or limited ventilation.

NEED OF CONTROL

The population, commerce, and industry in our urban areas is increasing at a very fast rate and can only be expected to continue to in-

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NEED OF CONTROL: Cont'd.

crease. Statistics are sometimes felt to be remote and uninteresting, but the statistics for the Province of Alberta and the larger urban areas of Calgary and Edmonton are very significant to the subject of air pollution.

This rapid expansion in urban areas not only in Alberta but throughout the world means that there are a greater number of sources of air contaminants which may pollute the atmosphere. This pollution will affect us in two ways; firstly, there will be the direct effect on properties immediately adjacent, and with the continued development of the area, there will be fewer and fewer cases where the adjacent property is not developed. Secondly, there will be the cumulative effect of all the 'sources' within the metropolitan area and as the area becomes larger this is a very real consideration.

During the past few years almost every large urban area in the world has experienced a drastic increase in the pollution of its atmosphere. As the discomforts of air pollution become more noticeable, public clamor for rigid regulation of air contaminating processes increases steadily.

METHODS OF CONTROL

Since it is difficult in generalizing all plants' sources and controls under a single report, this section is indicative of the means that can be taken of controlling air pollution sources.

I Fundamental Approaches to Control:

Regardless of the air pollution problem to be attacked . . that is, whether it be a community-wide problem or merely a single-source problem . . there are two fundamental approaches to control, the first being control of the pollutant at the source so that excessive amounts are not emitted to the atmosphere in the first place and the second is natural dilution of the pollutant after it has been emitted to the atmosphere to such a concentration that man, animals, vegetation, and materials will not be harmed.

II Control of the Pollutant at the Source:

Control of the pollutant at the source may be accomplished by keeping the pollutant from coming into existence or if it comes into existence, destroy, alter, or trap it before it can get out into the atmosphere.

The most positive way to abate air pollution is to keep the pollutant from coming into existence; or if this is impossible, to keep the quantity that does form to a bare minimum. For industries already in operation, this may be done by:

a) Raw material changes

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METHODS OF CONTROL

II Control of the Pollutant at the Source: Cont'd.

b) Operational changes

c) Modification or replacement of process equipment

d) Adopting an alternate method to produce the same product with fewer atmospheric wastes

e) More efficient operation of existing equipment

For industries developing entirely new products or processes, it is important to think about pollution problems in the research laboratory. With such an approach:

a) It may be found that, when looked upon from an air pollution angle, other lines of research differing from those being followed, may prove more promising.

b) Or, by developing a more expensive process, but one which reduces or eliminates the need for air pollution control equipment, it may be found that the overall production costs will be cheaper.

c) If the pollutant cannot be prevented from forming, and its uncontrolled mass rate of emission to the atmosphere is excessive, equipment which destroys, alters, or traps the pollutant will be required.

There are several basic methods of reducing a pollutant to tolerable levels of concentration before it is emitted from the stack top and these are destroy, mask, counteract, or collect the pollutant.

III Control by Dilution in the Atmosphere:

The best method of controlling air pollution confines the contaminant at its source. However, a second method, that of natural dilution of the pollutant in the atmosphere before it can reach the receptor in harmful concentrations, is also used. The natural dilution of contaminants can be accomplished by use of tall stacks, community planning in which zoning the use of the air is the primary object or effect meteorological control of the process operations.

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AIR POLLUTION CONTROL IN ALBERTA

AIR POLLUTION CONTROL SECTION

The Air Pollution Control Section is one of six sub-sections of the Environmental Health Services Division in the Alberta Department of Health and the Head of the Air Pollution Control Section reports directly to the Director of the Division. Besides the Head, this Section is staffed by four engineers, two environmental engineering technicians, four industrial laboratory technicians, one laboratory assistant and at least two engineering summer students. The services of the Environmental Health Laboratory are also utilized by the Air Pollution Control Section.

Basically the function of the Air Pollution Control Section is to develop and adminster programs for the assessment and control of air pollution in Alberta. This is done by regulating the pollution from industrial plants, assessing and reducing, where necessary, the emission of pollutants from various industrial operations and assessing the level of pollution in the vicinity of industrial operations and urban areas. Research programs sponsored by the Department of Health and carried out on our behalf are continually reviewed. These projects include the meteorological studies being done in Calgary and Edmonton and the mathematical modelling of dispersion calculations of pollutants.

Air Pollution Control in Alberta is governed by provincial legislation and the Regulations as such apply equally throughout the province.

LEGISLATION AND REGULATIONS IN THE PROVINCE OF ALBERTA

Legislation for the control of air pollution in Alberta has developed as the need, or anticipated need, arose. The first piece of legislation was to provide machinery to evaluate complaints and the remedy for correcting the conditions where necessary. A second item referred specifically to blowing dust from piles of coal and slag. These were enacted in 1945 and 1946 respectively.

In 1955 the authority to make regulations was added and in 1962 this was amended to include pipelines as an item subject to control as to operation and location.

The penalty for non-compliance with a Provincial Board of Health Order or with a rule or regulation for the Control of air pollution was set at the rate of up to $500 per day in 1955.

The first specific regulations for the control of air pollution were formulated in 1961 and became effective on September 15th of that year. These define air pollution and air contamination as follows:

> "Air Pollution" means the presence in the outdoor atmosphere of any air contaminant in quantities that may cause discomfort to persons or endanger their health or safety, or that may cause injury or damage to property or to plant or animal life.

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AIR POLLUTION CONTROL

IN

ALBERTA

> "Air Contaminant" means any solid, liquid or gas or combination of any of them in the outdoor atmosphere resulting from the activities of man.

A basic requirement of the regulations is the submission of plans and specifications for all new industries and incinerators (except those for single family residences) to the Provincial Board of Health for approval. Existing air pollution sources were given five years in which to arrange compliance with the regulations.

The standards for air pollution control are set out in four sections:

1. Smoke: as measured by Ringelmann Chart or equivalent with limits as to density and duration in urban and rural areas.

2. Particulates: as an emission standard of 0.85 lbs./1000 lbs. of flue gas adjusted to 50% excess air for the following three operations: 1) Combustion, 2) Incineration, 3) Processing and Manufacturing.

3. Odorous Material: as an effect standard as to use and enjoyment of property and the health or safety of the public.

4. Toxic or Noxious Materials: release is specifically subject to written approval by the Provincial Board of Health. Such approvals are based on the "calculated" maximum ground level concentration of the material which will occur.

It should also be added that the Board may vary specific limits respecting particulates and smoke where the Board is satisfied that such variation is in the public interest due to location, permanency of the operation, specific estimated effect of the air effluent or other factors deemed to be pertinent.

APPLICATION FOR APPROVAL

The method of applying for an Air Pollution Control Approval varies as to detail from one industry to another, but all include a process summary and flow sheet, with material balances, and information on the volume, temperature, velocity, contaminant concentration and stack height at each point of emission.

A follow-up to the Air Pollution Approvals is made in two ways:

1. A periodic assessment of the emissions is made by actual measurement of the emissions. In the case of larger sources this is once per year.

2. Area monitoring for the specific contaminants involved. This has been done in two ways up to the present, the monthly measurements such as exposure cylinders for H_2S and SO_2, lime papers for fluorides and dustfall cans for particulates. Continuous monitoring analyzers are used for H_2S, SO_2, smoke, oxides of nitrogen and oxidants.

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AIR POLLUTION CONTROL & REQUIREMENTS AT GAS PROCESSING & SULFUR RECOVERY PLANTS

Regarding air pollution at gas processing and sulfur recovery plants the Provincial Board of Health Regulations cover this aspect only generally but some of the acceptable pollutant concentrations resulting from gas plant operations are:

1. Sulfur Dioxide:

   a) 0.2 ppm as maximum ground level concentration in populated areas and in areas where vegetation is of commercial importance, that is, agricultural crops.

   b) 0.3 ppm as maximum ground level concentration in areas with little or relatively no population but where vegetation, such as timber, is potentially valuable. In areas with valuable timber the maximum ground level concentration shall apply at tree top level instead.

   c) 0.4 ppm or higher (as conditions may warrant) as maximum ground level concentration in areas with no population and with scrub vegetation.

2. Hydrogen Sulfide:

   Maximum ground level concentration is 0.01 ppm except in very remote areas. The present requirement is that H_2S effluents be incinerated to SO_2 before being released to the atmosphere.

3. Sulfur Trioxide:

   Maximum ground level concentration is 10 micrograms per cubic meter (1 microgram/M^3 seems achievable).

As mentioned above the present requirement is that all tail gas from sour gas processing plants (gas containing hydrogen sulfide) be incinerated to convert all H_2S to SO_2 and then exhausted to the atmosphere at a temperature of at least 1000°F through a stack of sufficient height so as to give resulting maximum ground level concentrations of SO_2 within the above prescribed limits. The computational methods that we use for estimating the expected ground level pollutant concentration and thus the estimation of stack height required are the Sutton Equation with the Lowry Modification for the case of even ground and the Pasquill Method for the case of uneven ground.

Another requirement is that all plant emergency releases of sour gas be flared in specially designed flare stacks with an adequate amount of fuel gas so as to ensure the successful flaring of gases with low heat-

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AIR POLLUTION CONTROL & REQUIREMENTS: Cont'd.

ing values. Experience has shown that a minimum of 250 B.T.U./ft.^{3} of gas going to the flare should be maintained. Again, depending on the length of flaring and the amount of gas to be flared the height of flare stack is usually designed so that the resulting maximum ground level SO_2 concentration does not exceed 0.2 ppm for flaring greater than one hour and 1 ppm for flaring less than one hour.

Whenever condensate is stored at the gas processing plant site a further requirement is that the true vapor pressure of the stored condensate does not exceed 12 psia. This is required so that evaporative hydrocarbon emissions to the atmosphere may be reduced to a minimum.

Another requirement is that odors be eliminated or reduced so as not to create a nuisance in the general vicinity of the plant.

How much Sulphur - Total quantity released - not only Concentrations

① Tonnage of Sulphur released.

② Concentrations of SO_2

APPROVAL

GUIDELINES

Approval Guidelines

APPROVAL GUIDELINES

In order to reduce the possibility of air pollution in Alberta the Provincial Board of Health may require any person or corporation proposing or planning to construct a pipe line which will contain dangerous or noxious materials or an industrial plant, or other premises, which may be a source of air pollution to submit plans and specifications for the proposed facilities to the said Board for review before construction is commenced. Such plans and specifications shall be in such detail as the Provincial Board of Health may require, but in any event shall show the proposed location of the facility and its size, capacity, and the nature of the processing, manufacturing or other operation. No construction shall be undertaken or proceeded with until approval in writing of the proposed construction has been granted by the Provincial Board of Health and the Provincial Board of Health may direct such changes as to the location and in the plans and specifications submitted for review as the said Board deems necessary in the public interest.

As regards approvals for proposed sour gas processing and sulfur recovery plants the procedure for approval application can be divided into two stages consisting of the following steps:

Stage I - Application for Provisional Approval

1) The company concerned notifies the Environmental Health Services Division of its wish to construct and operate a gas plant at a certain location in Alberta. The legal description and a contour plot plan of the proposed plant site is supplied.

2) Preliminary plant design information, including:

   a) Plant maximum raw gas inlet rate, MMSCFD (60°F & 14.7 psia).
   b) Raw gas hydrogen sulfide content, mole %.
   c) Plant sulfur recovery efficiency based on sulfur in raw gas, %.
   d) Incinerator stack height and top internal diameter, ft.
   e) Incinerator stack flue gas volume, sulfur dioxide content, and temperature and velocity upon stack exit, based on plant maximum operating conditions.

   is prepared by the prospective owner and forwarded to the Environmental Health Services Division.

3) The plant owner reviews the proposed site in the field with an engineer from the Department of Health Air Pollution Section.

4) The Environmental Health Services Division reviews the submission and assesses the adequacy of the proposed facilities to control air pollution. Discussions may be held with company representatives regarding questionable or contentious aspects.

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Stage I - Cont'd.

5) Upon the Provincial Board of Health's satisfaction that the preliminary design information indicates that adequate air pollution control measures will be instituted the Provincial Board of Health issues a Provisional Air Pollution Approval enabling the owner to proceed with the final plant design.

Stage II - Application for Final Approval

1) Final plant design information, including:

   a) Plant schematic flow sheets and plant material balances of the raw feed and all products and effluents. The disposal of all gaseous wastes shall be described in detail including volume, composition and temperature. Special mention should be made of mercaptans, hydrogen sulfide, sulfur dioxide and other odorous gases.

   b) Plans of incinerator stack indicating height, top internal diameter, location, number and size of stack sampling ports, sampling platform and access ladder, 110 volt electrical outlet location, and stack top temperature censor location.

   c) Emergency flare stack heights and maximum amount of sour gases to be flared.

   is submitted to the Environmental Health Services Division.

2) Other pertinent information required at this time is:

   a) A plot plan of plant area and surrounding vicinity indicating the proposed exposure cylinder (hydrogen sulfide and sulfur dioxide) station network.

   b) Condensate storage true vapor pressure.

3) Upon the Provincial Board of Health's satisfaction that adequate measures will be instituted to control air pollution to acceptable levels for the particular plant area the Provincial Board of Health issues a Final Air Pollution Approval and construction and subsequent operation of the proposed gas processing and sulfur recovery plant may commence.

The Provisional Air Pollution Approval means that the basic points of concern such as plant location, pollutant effluent volume, and

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APPROVAL GUIDELINES: Cont'd.

expected maximum ground level pollutant concentration have been checked while the Final Air Pollution Approval means that a final check on these basic points has been made together with a review of all the other pertinent plant details and includes a list of various operating, reporting, and monitoring requirements once the plant is in operation. These other requirements cover emergency flaring of sour gases, monitoring of the atmosphere and stack sampling and submission of reports.

The submission applications for approval should be sent to the Environmental Health Services Division, Department of Health, Administration Building, Edmonton 6, Alberta.

CONSIDERATIONS IN DESIGNING A SOUR GAS PROCESSING PLANT

Read

1) The major contributor to air pollution from a sour gas processing and sulfur recovery plant is the tail gas from the sulfur recovery plant. This gas usually has a high content of sulfur gases in the form of H_2S and SO_2 along with other gases such as CO_2, H_2O, O, N_2 and O_2. Whenever the control of pollutants at their source is not feasible then a second method, that of natural dilution of the pollutant in the atmosphere before it can reach the receptor, is usually used. Since SO_2 odors are more tolerable than H_2S odors the tail gases are incinerated to convert all H_2S to SO_2. To aid the combustion of sour gases and because hot gases are more boyant than cool gases residue (fuel) gas is added to the incineration process in amounts sufficient to exhaust the incinerator flue gases to the atmosphere at a temperature of at least 1000°F. From the incinerator the combusted tail gas is vented through a stack of sufficient height to give resulting maximum ground level concentrations of SO_2 within prescribed limits. The computational methods used by the Environmental Health Services Division for the estimation of expected ground level pollutant concentration and thus the estimation of stack height required are the Sutton Equation using the Lowry Modification for the case of even ground and the Pasquill Method for the case of uneven ground.

[illegible]

Computational outlines for computing ground level pollutant concentrations by the Sutton Equation using the Lowry Modification and the Pasquill Method are included in Appendix A and copies of Department of Health Computer Programs No. SH505 (Calculation of Ground Level Pollutant Concentrations from Elevated Sources employing the Sutton Equation using the Lowry Modification) and No. SH510 (Calculation of Ground Level Pollutant Concentrations from Elevated Sources employing the Pasquill Method) are included in Appendix B.

[illegible] No [illegible] Emission Standards [illegible] plants

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CONSIDERATIONS IN DESIGNING: Cont'd.

2) A second large source of air pollution at sour gas processing and sulfur recovery plants is the flaring of emergency releases of sour gas. Although this may not be considered a continual large source it may become one if plant upsets force the flaring of raw sour gas or acid gas. Since both gases have a high H_2S content the requirement is that they be flared in specially designed flare stacks with an adequate amount of residue (fuel) gas so as to ensure the successful flaring of gases with low heating values. Experience has shown that a minimum of 250 B.T.U./ft.^{3} of gas going to the flare should be maintained and the flare pilot light should be relatively non-extinguishable so as to ensure that the combustible gases reaching the flare are immediately ignited. Depending on the length of flaring and the amount of gas to be flared the height of the flare stack is usually designed so that the resulting maximum ground level SO_2 concentration does not exceed 0.2 ppm for flaring greater than one hour and 1 ppm for flaring less than one hour.

A computational example illustrating the method of flare stack calculation is included in Appendix C and copies of Department of Health Computer Programs No. SH508 (Calculation of Ground Level Pollutant Concentrations from Flares Employing the Sutton Equation using the Lowry Modification for the case of even ground) and No. SH507 (Calculation of Ground Level Pollutant Concentrations from Flares Employing the Pasquill Method for the case of uneven ground) are included in Appendix D. A graphical method for calculating the required residue (fuel) gas rates for flaring various rates of H_2S with various flare stack heights is included in Appendix E.

3) The Sutton equation gives the maximum one-half hour ground level pollutant concentration to be expected on the axis of the plume at a distance from the source where the maximum is supposed to occur. Generally, the distance from the source is from ten to twenty effective stack heights but in any case will vary with wind speed and turbulence. The Pasquill Method gives the ground level axial pollutant concentration at any specified distance from the pollutant source and compensates for the difference in elevation between the receptor and source, if any. It is felt that the ground level pollutant concentration given by the Pasquill Method is also the maximum one-half hour concentration since good correlation is obtained when comparing with results from the Sutton equation but this assumption is not corroburated by the literature.

4) The effective stack height is the sum of three terms - the actual stack height, the rise caused by the velocity of the stack gases, and the rise attributable to the density difference between the stack gases and the atmosphere.

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CONSIDERATIONS IN DESIGNING: Cont'd.

5) The effect of temperature in itself, that is, comparing winter to summer conditions, is not as important as the temperature gradients. Soon after the gases leave the stack they approach the temperature of the surrounding air through mixing. In the theoretical equations the ambient temperature is included. It has been the practice in Alberta to consider a temperature of 70°F. This assumption would make the ground concentration slightly higher than that computed using a winter temperature, however the summer period is the one which is usually considered the critical one insofar as crop damage is concerned.

6) The location of the maximum ground level concentration is a function of atmospheric stability. During unstable atmospheric conditions (high turbulence) the maximum occurs relatively close to the stack. As the atmosphere becomes increasingly stable, the location of the maximum ground level concentration moves further away from the stack.

7) Average concentrations of a contaminant downwind from a stack are directly proportional to the discharge rate. An increase in discharge rate by a factor increases ground level concentrations at all points by the same factor. The discharge rate, Q, should be calculated at atmospheric temperature (70°F).

8) Average downwind concentrations are inversely proportional to the square of the effective stack height. Doubling the effective stack height reduces maximum ground level concentrations to one quarter of the original value.

9) For equivalent effective stack heights, average downwind concentrations are inversely proportional to the wind speed. An increase in wind speed by a factor of two, reduces ground level concentrations by one-half.

10) Whenever two or more stacks are closely grouped they have mutual influences (the plumes tend to merge into one) and the total pollutant ground level concentration at any point is equal to the sum of the pollutant ground level concentrations from the individual stacks at that point.

11) The incinerator stack should preferably be located on the highest point of the plant site so as to gain as much height for pollutant emission as possible.

12) Wherever valuable timber stands exist the allowable ground level pollutant concentration for that area shall apply at tree top level instead.

. . . K6

CONSIDERATIONS IN DESIGNING: Cont'd.

13) Incinerator stack sampling ports should be located about eight to ten diameters from any stack features which may disturb the uniformity of the velocity profile, that is, bends, enlargements, contractions and entry or exit ports. The usual location is at about mid stack height.

14) The incinerator stack sampling ports must be large enough to accommodate sampling probes (pitot tube, etc.) without damaging them when they are being inserted. The size of the sampling port depends largely on the thickness of the wall of the stack. For example a 'thin' wall may require a port of only about three inches diameter whereas a wall of about twelve inches may require a port eight inches in diameter.

15) For small incinerator stacks (10 foot external diameter or less at sampling port location) usually two sampling ports at 90° to each other are sufficient. For stacks larger than 10 foot external diameter four sampling ports at 90° to each other should be provided. Suitable flanged port covers should also be provided.

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APPENDIX A

COMPUTATION BY SUTTON EQUATION USING THE LOWRY MODIFICATION

The maximum $\frac{1}{2}$ hour downwind ground level concentration by the Sutton equation is:

$$C_{max}\,(\text{ppm}) = \frac{2Q\,10^6}{e\pi\,He^2} \times \frac{Am}{U}$$

$$= 2.35 \times 10^5 \left\{ \frac{Q}{He^2} \times \frac{Am}{U} \right\}$$

where C_{max} = maximum $\frac{1}{2}$ hour ground concentration expected on the axis of the plume at a distance from the source where the maximum is to occur (generally ten to twenty effective stack heights from source), ppm by volume.

Q = total contaminant emission rate at 70°F, c.f.s.
U = wind speed, f.p.s.
He = effective stack height, ft.
Am = factor representing the frequency of the most frequent wind direction.

If the stack gases are at an elevated temperature or have an appreciable exit velocity from the stack, the effective stack height is greater than the physical stack height because of buoyancy and jetting action and is given by the following formula:

$$He = hs + 0.75\,(hv + ht)$$

where He = effective stack height, ft.
hs = physical stack height, ft.
hv = flue gas velocity rise, ft.
h_t = flue gas thermal rise, ft.

The temperature and velocity rise are not constant for given stack conditions but depend on the wind speed and atmospheric - temperature lapse rate. The equation developed by Bosanquet for the maximum rise caused by the velocity of the stack gases is:

$$hv = \frac{4.77}{1 + 0.43\,\frac{U}{V_s}} \left(\frac{\sqrt{QT_1 \cdot V_s}}{U} \right)$$

where hv = maximum velocity rise, ft.
U = wind speed, f.p.s.
V_s = exit velocity of stack flue gases, f.p.s.
QT_1 = total stack flue gas flow rate at ambient conditions (70°F), c.f.s.

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SUTTON EQUATION: Cont'd.

The Bosanquet expression for maximum thermal rise is:

$$h_t = 6.37 \text{ g } \frac{QT_1 \cdot \Delta \cdot Z}{U^3 T_1}$$

$$= 0.387 \frac{QT_1 \cdot \Delta \cdot Z}{U^3}$$

where h_t = maximum thermal rise, ft.
T_1 = temperature at which stack gas density equals that of the ambient air (70°F), °R.
Δ = temperature difference between stack flue gases at exit and ambient air, °F.
$Z = \ln J^2 + \frac{2}{J} - 2$

$$J = \frac{U^2}{\sqrt{QT_1 \cdot V_s}} \left(0.43 \sqrt{\frac{T_1}{gG}} - 0.28 \frac{V_s}{g} \frac{T_1}{\Delta} \right) + 1$$

or

$$J = \frac{U^2}{\sqrt{QT_1 \cdot V_s}} \left(0.43 \sqrt{\frac{T_1}{gG}} - 4.609 \frac{V_s}{\Delta} \right) + 1$$

G = the gradient of potential atmospheric temperature, °F/ft.
g = acceleration due to gravity, 32.17 ft./sec.^{2}

Normally only 75% of the velocity and thermal rise is used because utilization of the full thermal and velocity rise can never be achieved. The critical wind speed for a given stack is estimated by calculating the maximum ground-level concentrations for a number of different wind speeds with appropriate effective stack heights.

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The following values of constants are listed for use with the Sutton Equation

Wind Speed m.p.h.	5	10	15	20	25
u, ft./sec.	7.34	14.67	22.0	29.34	36.67
u^2	53.8	215	484	861	1,345
u^3	395	3,155	10,650	25,200	49,300
C_z/C_y	0.50	0.50	0.25	0.15	0.15
a_m/u	0.068	0.034	0.0114	0.0051	0.0041
$0.43\sqrt{\frac{T_1}{gG}}$	16.787	20.558	23.740	41.121	55.169

Useful Forms

Q_{T_1} = ______________ c.f.s. @ 70°F & 14.7 psia

T_1 = 70°F. or 530°R v_s = _____________ ft./sec.

$\sqrt{Q_{T_1} v_s}$ = _____________   = ______________

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COMPUTATION OF THERMAL RISE

1. u ft./sec.	7.34	14.67	22.0	29.34	36.67
2. .43 T_1/gG	16.787	20.558	23.740	41.121	55.169
3. 4.609 $\frac{V_s}{\Delta}$					
4. (2) - (3) =					
5. $u^2/\sqrt{Q_{T_1} V_s}$					
6. (4) x (5) =					
7. +	1.0	1.0	1.0	1.0	1.0
8. J = ((6) + (7)) =					
9. 4.60 $\log_{10} J$					
10. 2/J					
11. (9) + (10)					
12. -	2.0	-2.0	-2.0	-2.0	-2.0
13. Z = (11) - (12) =					
14. Z/u^3 =					
15. .387 $Q_{T_1} \Delta$ =					
16. h_t = (14) x (14)					

. . . K11

COMPUTATION OF VELOCITY RISE

u ft./sec.	7.34	14.67	22.0	29.34	36.67
1. $u/v_s \times .43$ =					
2. $\frac{4.77}{1 + .43 \frac{u}{v_s}}$ =					
3. $\frac{\sqrt{Q_{T_1} \; v_s}}{u}$ =					
4. $h_v = (3) \times (2) =$					

COMPUTATION OF Co_{max}

1. $h_v + h_t$					
2. $0.75\ (h_v + h_t)$					
3. h_s					
4. $H_e = (2) + (3)$ =					
5. H_e^2					
6. $2.35 \frac{a_m}{u}$	.160	.080	.0268	.0120	.0096
7. $Co_{max} = Q \times 10^5\ (6)/(5)$					

. . . K12

COMPUTATION BY PASQUILL METHOD

The formula for estimating the distribution of ground concentrations downwind of a source of air-borne material as outlined in a paper by Pasquill is:

$$Co(ppm) = \frac{1.68 \times 10^8 \times Q}{U\ d\ \theta\ h}$$

where Q = contaminant emission rate at ambient conditions (70°F), cfs.
U = wind velocity, f.p.s.
d = distance from source along axis of plume of point of concern, ft.
θ = lateral spread of plume at distance 'd', degrees.
h = vertical spread of plume at distance 'd', ft.

This method gives the concentrations specifically in terms of the vertical spread of the plume (h). The magnitude of h initially increases with the distance d from the source and varies according to the rapidity with which the vertical mixing occurs in the atmosphere. Tentative estimates of h over a range of distance 330 ft. to 330,000 ft. are given in Figure 1, for 6 categories of stability which are broadly specified below in terms of wind speed, insolation and state of sky. 'Strong' insolation is intended to refer to sunny middle-of-day conditions in mid-summer, while 'slight' insolation refers to corresponding conditions in mid-winter.

KEY TO STABILITY CATEGORIES IN FIGURE 1

TABLE 1

Surface Wind Speed, f.p.s.	Strong Insulation	Moderate Insulation	Slight Insulation	Heavily Overcast, Day or Night	Thinly Overcast or > 4/8 low cloud, night	< 3/8 cloud, night
< 6.5	A	A-B	B	D	–	–
6.5	A-B	B	C	D	E	F
13	B	B-C	C	D	D	E
20	C	C-D	D	D	D	D
> 20	C	D	D	D	D	D
	unstable conditions			neutral conditions	stable conditions	

(For A-B take average of figures for A and B, etc.)

PASQUILL METHOD: Cont'd.

The values of lateral spread θ for the two extreme distances 330 ft. and 330,000 ft. are estimated in Table 2. Values at approximately equal intervals between these should be taken for intermediate distances 3,300 ft. and 33,000 ft.

TABLE 2

Stability Category	d = 330 feet θ	d = 330,000 feet θ
A	50°	25°
B	40°	20°
C	30°	15°
D	20°	10°
E	15°	7°
F	10°	5°

The axial concentration Co for an emission rate of Q c.f.s. may now be calculated from the Pasquill equation by substituting the distance d, the estimated values of h and θ and the appropriate value of wind velocity U. The surface wind speed should be used for the short distance (330 ft.) and an estimated mean value between surface and geostrophic wind velocities throughout the main depth of the cloud for the extreme distance of 330,000 ft.

If the source is elevated the concentrations at ground level will be reduced at the shorter distances but will tend more closely to the ground values as distance is increased. Correction factors F_1 as a function of h/H, where H is the height of the source, are given in Table 3 below, and these should be used to multiply the previously derived values of Co. For this purpose it will usually be necessary to take values of h at shorter intervals and this of course can be done using Figure 1.

TABLE 3

h/H	F_1
0.4	5.6×10^{-7}
0.5	1.0×10^{-4}
0.6	1.7×10^{-3}
0.7	9.0×10^{-3}
0.8	0.027
0.9	0.057
1.0	0.10

. . . K14

PASQUILL METHOD: Cont'd.

TABLE 3 - Cont'd.

h/H	F_1
1.5	0.36
2.0	0.56
3.0	0.77
4.0	0.87
5.0	0.91
10.0	0.98

EXAMPLE OF CALCULATION OF DISTRIBUTION OF GROUND CONCENTRATIONS

Data

Emission rate, $Q = 1.15$ c.f.s. of SO_2
Wind velocity, $U = 14.67$ f.p.s.
Stability category, C (Table 1)
Effective stack height, $H = 202$ feet.

Calculation of Co for Ground Release

Distance in ft., d	300	3000	30,000
Vertical Spread, h (Figure 1)	48	375	3000
Laterial Spread, θ (Table 2)	30°	30°	30°
Co, ppm	30.5	0.39	0.0049

Allowance for Elevation of Source

h/H	0.5	0.8	1.5	2.0	4.0
F_1 (Table 3)	1×10^{-4}	0.027	0.36	0.56	0.87
h, ft.	101	162	303	404	808
d, ft. (Fig. 1)	690	1130	2350	3250	7100
θ (Table 2)	30°	30°	30°	30°	30°
Co, ppm	6.3	2.4	0.62	0.33	0.077
F_1 x Co, ppm	0.00063	0.065	0.223	0.19	0.067

Concentrations for other wind velocities are calculated in the same manner.

. . . K15

ESTIMATES OF VERTICAL SPREAD - h

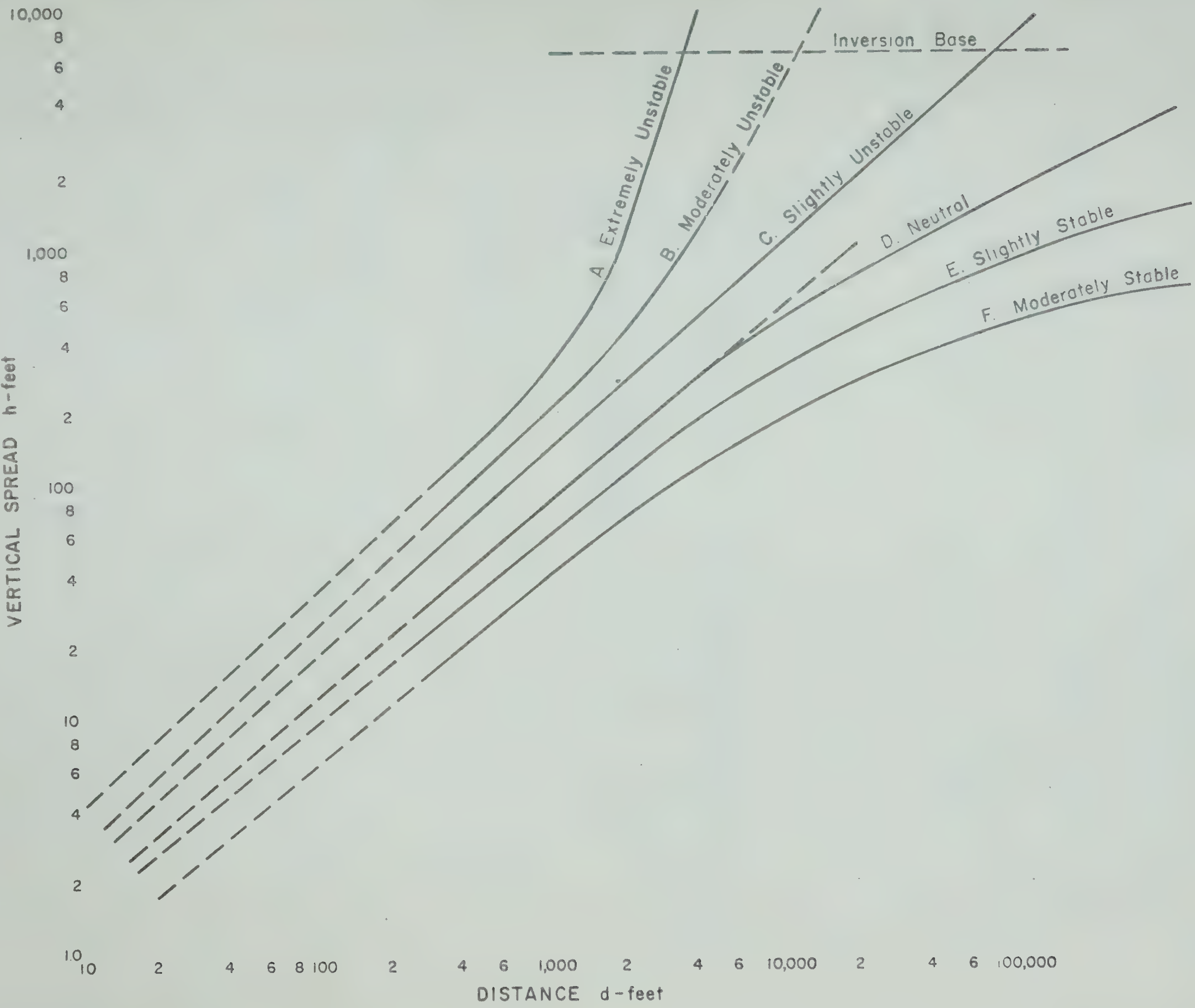

FIGURE I

F.16.73-6

K16

APPENDIX B

PROGRAM: SH505

PROGRAM TITLE:

DEPARTMENT OF HEALTH
Stack Calculations
Calculation of Ground Level Concentrations from Elevated Sources (Stacks).

Case No. 1 - Strong Inversion
Case No. 2 - Adiabatic Atmosphere

DATE: December 1964

BY: E. Kupchanko

1.0 SCOPE OF PROGRAM

1.01 Purpose

1.011 Problem Description

This program was designed to calculate the maximum pollutant gas concentration and the distance to the maximum for varying stack heights, wind velocities at any set of constant exit gas velocities, total gas flow rates and contaminant gas flow rates. It is in two parts, Case No. 1, Moderately stable condition, and Case No. 2, moderately unstable condition. Both parts are calculated simultaneously.

1.012 The advantages of this program are that it can be set up very quickly (2 cards for each set of conditions) and that it solves problems quickly.

1.02 Method

1.021 Method of Solution Programmed

This air pollution program calculates the maximum pollution gas concentration at ground level, and the distance from the stack at which it occurs using the Sutton equation with the Lowry modification (1).

$$Co_{max}\ (\text{ppm}) = 2.35 \times 10^5 \left(\frac{Q}{He^2} \cdot \frac{Am}{U} \right) \qquad (1)$$

where He = equivalent stack height defined by (2)

$$He = h_s + .75\ (hr + ht) \qquad (2)$$

where h_s = stack height (ft.)

. . . K17

1.0 SCOPE OF PROGRAM

1.021 Method of Solution Programmed - Cont'd.

h_r = velocity rise; distance the gas rises in the atmosphere because of its momentum.

h_t = thermal rise; distance the gas rises in the atmosphere because of its elevated temperature.

Q = contaminant gas flow rate at ambient conditions.

U = wind velocity (ft./sec.).

Am = a function of wind velocity.

Calculation of Velocity Rise, h_v

$$h_v = \frac{4.77}{1 + .43\ U/Vs} \left(\frac{\sqrt{Qtl.Vs}}{U} \right) \qquad (3)$$

where Qtl = total gas flow rate from stack $ft.^3/sec.$ at ambient conditions.

Vs = velocity of gas in stack, ft./sec.

Calculation of Thermal Rise, h_t (Case No. 1)

$$h_t = .387\ Q_{T1}\ \Delta\ Z/U^3 \qquad (4)$$

where Δ = difference T°F between air and stack gas temperatures.

$$Z = \ln J^2 + \frac{2}{J} - 2$$

$$J = \frac{U^2}{\sqrt{Qtl\ Vs}} \left(.43 \sqrt{\frac{T1}{gG}} - .28\ \frac{Vs}{g}\ \frac{T1}{\Delta} \right) + 1$$

g = acceleration due to gravity 32.17 $ft./sec.^2$

G = Gm, a function of wind velocity.

T1 = temperature at which stack gas density equals that of atmosphere.

T2 = stack gas temperature.

. . . . . K18

1.0 SCOPE OF PROGRAM

1.021 Method of Solution Programmed - Cont'd.

Calculation of Thermal Rise, h_t (Case No. 2)

$$h_t = .387\ Qtl \Delta Z/U^3$$

$$X = \frac{xU}{3.57\sqrt{Qtl \cdot Vs}}$$

where Δ = difference T•F between air and stack gas temperatures.

The relation between X and Z is shown on the graph Bosanquet Thermal rise parameters for an adiabatic atmosphere.

Calculation of Distance to Maximum Concentration - Cases 1 and 2

$$\text{Case 1} \quad X = 20\ He$$
$$\text{Case 2} \quad X = 10\ He \qquad (5)$$

where X = distance from stack at which maximum pollutant concentration occurs (ft.).

He = effective stack height.

2.0 LIMITATIONS

2.01 For any one set of problems the maximum number of stack heights is 6, maximum number of wind velocities is 10; no more than 99 sets of conditions may be solved at one time. Wind velocities and diffusion parameters are fixed although may be changed internally in the program.

3.0 PROGRAM USER INFORMATION

3.01 Input Data

Card #	Column	Format	Name	Unit	Description
1	1-2	2I	KA		Number of sets of data
1	3-4	2I	KZ		Number of stack heights
2	2-80	79H	ID		User's identification of problem

. . . K19

3.01 Input Data: Cont'd.

Card #	Column	Format	Name	Unit	Description
3	1-7	F7.1	QT1	cfs	Total gas flow rate at T1
	8-14	F7.1	VS	fps	Exit gas velocity
	15-21	F7.0	T2	°F	Temperature of gases
	22-28	F7.0	T1	°F	Temperature at which the stack gas density equals that of atmosphere
	29-35	F7.2	QS02	cfs	Contaminant gas flow rate
	36-78	F7.0	SH(g)	ft.	Jth stack height (no more than 6)

ID Card must always precede data card.

3.02 Output

3.021 Explanation of Output

Output of Input Data	Units	Symbol Used in Program	Symbol Used in Write-up
Identification			
Stack Height	ft.	HS(J)	h_s
Exit Gas Velocity	fps	VS	V_s
Total Gas Flow Rate	cfs	QT1	Q_{t_1}
Wind Velocity	fps	U(I)	U
Stack Gas Temperature	°F	T2	T_2
Temperature at which stack gas density equals that of atmosphere	°F	T1	T_1
Contaminant Flow Rate	cfs	QS02	Q

. . . K20

3.02 Output

3.021 Explanation of Output: Cont'd.

Calculated Output	Units	Case 1	Case 2	Symbol Used in write-up
Thermal Rise	ft.	AHT(I)	BHT(I)	H_t
Velocity Rise	ft.	AHV(I,J)	AHV(I,J)	H_v
Equivalent Stack Height	ft.	ES(I)	EHS	H_e
Maximum Concentration	PPM	CMAX	CMAZ	Comax
Distance to Maximum Concentration	ft.	D(I,J)	DIS(I)	X

3.03 No programmed stops.

4.0 OPERATION DETAILS

4.01 No sense switch settings.

4.02 No operator instruction card.

```
.FLAG   JOB.C).SH50[illegible]
.FLAG FORTRAN,COMPILE,SH505
C       DEPT.OF PUBLIC HEALTH STACK CAL[illegible]LATIONS. [illegible]
        DIMENSION U(10).AMU(10),SQ(10).AHV(10,6),[illegible]
       1(6),D(10,6),CMAX(10).DIS(10).PHZ(10),EXX(10).[illegible]
        [illegible]
        DO 99 L=1.KA
        READ(1,211)
        READ INPUT TAPE [illegible]
        U(1)=[illegible].
        [illegible](2)=[illegible].
        U(3)=7. [illegible]4
        U(4)=[illegible].00
        U(5)=14.67
        U(6)=2[illegible].00
        U(7)=22.00
        [illegible](8)=[illegible].34
        U(9)=36.67
        U(10)=44.00
        AMU(1)=0.500
        AMU(2)=0.100
        [illegible]( )=[illegible].068
        [illegible].056
        AMU(5)=0.034
        AMU(6)=0.0163
        AMU(7)=0.0114
        AMU(8)=[illegible].0051
        AMU(9)=0.0041
        AMU(10)=0.0034
        [illegible].7292
        SQ(2)=0.7292
        SQ(3)=0.7292
        [illegible](4)[illegible].[illegible]
        [illegible]
        [illegible]
        SQ(7)=1.0295
        SQ(8)=1.7862
        SQ(9)=2.3964
        SQ(10)=3.1057
  100 FORMAT(2F7.1,2F7.0,F7.2,6F7.0)
  111 FORMAT(18H0THERMAL RISE,F[illegible]. ,7X,10F9.0)
  112 FORMAT(18H0VELOCITY RISE,[illegible].,7X,10F9.0)
  113 FORMAT(18H0EFF.STACK [illegible],7X,10F9.0)
  114 FORMAT(18H0C[illegible]
  115 FORMAT(18H0DOWNWIND DISTAN[illegible], X,10F9.0)
  116 FORMAT(I2,I2,20X)
  201 FORMAT(62H1DEPARTMENT OF PUBLIC HEALTH, DIVISION OF [illegible]
     1EERING)
  202 FORMAT(65H CALCULATION OF GROUND LEVEL CONCENTRATIONS FRO[illegible] ELEVATE
     1D SOURCES)
  [illegible] FORMAT([illegible]CASE =1, [illegible] STABLE CONDITIONS,77X,I2)
  204 FORMAT(18H0WIND VELOCITY,FPS,7X,10(4X,F5.2))
  205 FORMAT(24H0    ELEVATION OF SOURCE  ,F4.0,3HFT.)
  206 FORMAT(40H1CASE =2, [illegible]ERATELY UNSTABLE CONDITIONS,75X,I2)
  208 FORMAT(1H0,6X,4HQT1 ,F7.1,4X,3HVS ,F5.1,4X,3HT[illegible] ,F[illegible]
     1[illegible],4X,5HQSO2 ,F6.2)
  209 FORMAT(53H      CASE =2 CALCULATIONS INVALID BELOW WIND SPEED OF [illegible]
     1.0,4HFPS.)
  211 FORMAT(80H
     1
```

. . . K22

```
WRITE OUTPUT TAPE 2,201
WRITE OUTPUT TAPE 2,202
[illegible]
WRITE(2,203)L
WRITE OUTPUT TAPE 2,204,(U(I),I=1,10)
[illegible]
T1=T1+460.
SQQV=SQRTF(QT1*VS)
DO 80 J=1,KZ
WRITE OUTPUT TAPE 2,205,SH(J)
DO 70 I=1,10
[illegible]
AHV(I,J)=(4.77/(1.+.42*U(I)/VS))*SQQV/U(I)
AJ=(U(I)**2/SQQV)*([illegible](I)-(.28*VS*T1/(32.17*DFL)))+1.
Z=[illegible]
AHT(I)=6.37*32.17*QT1*DFL*Z/(T1*U(I)**3)
FS(I)=0.75*(AHT(I)+AHV(I,J))+SH(J)
CMAX(I)=[illegible]
D(I,J)=[illegible]
WRITE [illegible]
WRITE(2,112)(AHV(I,J),I=1,10)
WRITE(2,113)(FS(I),I=1,10)
WRITE(2,114)(CMAX(I),I=1,10)
WRITE(2,115)(D(I,J),I=1,10)
CONTINUE
WRITE(2,206)L
WRITE OUTPUT TAPE 2,204,(U(I),I=1,10)
DO 81 J=1,KZ
WRITE OUTPUT TAPE 2,205,SH(J)
DO 7[illegible]
XA=D(I,J)
XB=[illegible]
IF([illegible]
ZB=XB/(2.172+.1[illegible]*XB)
GO TO 94
ZB=(LOGXF(XB)-.3553)/.2286
CONTINUE
BHT=6.37*32.17*QT1*DFL*ZB/(T1*U(I)**3)
FHS=.75*(BHT+AHV(I,J))+SH(J)
DIST=1[illegible].*FHS
TH=DIST-XA
IF(ABSF(TH)-XA/1000.)96,96,95
XA=XA+TH/2.
GO TO 91
DIS(I)=DIST
BHZ(I)=BHT
FXX(I)=FHS
CMAX(I)=[illegible]
WRITE(2,111)([illegible](I),I=1,10)
WRITE(2,112)(BHZ(I),I=1,10)
WRITE(2,113)(FXX(I),I=1,10)
WRITE(2,114)(CMAX(I),I=1,10)
WRITE(2,115)(DIS(I),I=1,10)
CONTINUE
VAA=[illegible]
VA=SQRTF(VAA)
WRITE OUTPUT TAPE 2,209,VA
T1=T1-460.
WRITE OUTPUT TAPE 2,208,QT1,VS,T2,T1,Q502
CONTINUE
END
```

PROGRAM: SH510

PROGRAM TITLE: Department of Health
Stack Calculations - Pasquill Method

DATE: August 1965

BY: E. Kupchanko

1.0 SCOPE OF PROGRAM

1.01 Purpose

1.011 Problem Description

This program was designed to calculate the estimation of downwind concentrations of air borne material. The method proposed gives concentrations specifically in terms of the vertical spread of the plume and the practical problem is thus transformed into making the best possible estimates of these quantities.

1.012 The program uses tabular data empirically derived together with theoroetical equations.

1.02 Method

1.021 Method of Solution Programmed

The program calculates the distribution of concentration downwind of a source using the method as outlined in a paper by Pasquill. (1)

$$Co\ (ppm) = \frac{1.68 \times 10^8 \times Q}{u\ d\ \theta\ h}$$

where Q = contaminant emission rate at ambient conditions

u = wind velocity (fps)

d = lateral distance from the source (ft.)

θ = lateral spread

h = vertical spread (ft.)

The magnitude of h initially increases with the distance d from the source and varies according to the rapidity with which the vertical mixing occurs in the atmosphere.

. . . K24

1.022 Key to Stability Factors

ISTAB	1	2	3	4	5	6
surface wind speed fps	Strong	Insolation Moderate	Slight	Heavily Overcast Day or Night	Thinly Overcast or>4/8 low cloud Night	<3/8 cloud Night
	KSTAB	KSTAB	KSTAB	KSTAB	KSTAB	KSTAB
fps						
< 6.5	1	1-2	2	4	-	-
6.5	1-2	2	3	4	5	6
13	2	2-3	3	4	4	5
20	3	3-4	4	4	4	4
> 20	3	4	4	4	4	4
	unstable conditions			neutral	stable conditions	

1.023 Estimation of the Lateral Spread θ

The values of θ for the two extreme distances, 330 feet and 330,000, were extrapolated from the various observations below.

Stability Category (ISTAB)	d = 330 feet	d = 330,000 feet
1	50°	25°
2	40°	20°
3	30°	15°
4	20°	10°
5	15°	7°
6	10°	5°

1.024 Allowance for Elevation of Source

If the source is elevated the concentrations at ground level will be reduced at the shorter distances but will tend more closely to the ground source values as the distance is increased. A correction factor is then used to multiply the derived values of Co.

$$F = \frac{1}{e^{(2.303\ H^2/h^2)}}$$

1.024 Allowance for Elevation of Source: Cont'd.

where F = correction factor

H = effective height of source

h = vertical spread

1.025 Thermal Rise

For strong, moderate, and slight insolation the thermal rise is obtained by the following equations for unstable conditions.

$$h_t = .387\ Qtl \Delta Z/u^3$$

$$X = \frac{xu}{3.57\sqrt{Qtl}\ Vs}$$

where Δ = difference (T°F) between air and stack gas temperatures

QT1 = total gas flow rate from stack (ft.^{3}/sec.) at ambient air conditions (70°F)

Vs = velocity of gas in stack (ft./sec.)

x = distance to point of maximum pollution

The relationship between X and Z is shown on the graph Bosanquet thermal rise parameters for an adiabatic atmosphere.

For heavy overcast day or night, thinly overcast or $>4/8$ low cloud, and $<3/8$ cloud night thermal rise is obtained by the following equations for stable conditions.

$$h_t = .387\ QT1 \Delta Z/u^3$$

where Δ = difference (T°F) between air and stack gas temperatures

QT1 = total gas flow rate from stack (ft.^{3}/sec.) at ambient air conditions (70°F)

$$Z = \ln J^2 + \frac{2}{J} - 2$$

$$J = \frac{u^2}{\sqrt{Qtl \cdot Vs}} \left(.43 \sqrt{\frac{Tl}{gG}} - .28 \frac{Vs}{g} \cdot \frac{Tl}{\Delta} \right) +1$$

. . . K26

1.025 Thermal Rise

where g = acceleration due to gravity 32.17 ft./sec.^{2}

G = Gm, a function of wind velocity

$T1$ = temperature at which stack gas density equals that of atmosphere (°F)

u = wind velocity (fps)

1.026 Velocity Rise

$$hv = \frac{4.77}{1 + .43\,u/V_s} \left(\frac{\sqrt{Qtl \cdot V_s}}{u} \right)$$

where Qtl = total flow rate from stack (ft.^{3}/sec.) at ambient conditions

V_s = velocity of gas in stack (ft./sec.)

u = wind velocity (ft./sec.)

2.0 LIMITATIONS

2.01 For any one set of problems the maximum number of wind velocities is 5; the maximum distances from the source is ten. The two extreme distances from the source are 330 feet and 330,000 feet.

3.0 PROGRAM USER INFORMATION

3.01 Input Data

Note: Control Card Each Set of Data, 2 - 3.

Card #	Column	Format	Name	Unit	Description
1	1-3	I3	KA		Number of sets of data
2	1-3	I3	KWIND		Number of wind speeds (maximum of 5)
2	4-6	I3	KDIST		Number of distances (maximum of 10)
2	7-9	I3	KB		Lower stability number
2	10-12	I3	KC		Higher stability number (KC > KB)
2	13-18	F6.0	SH	ft.	Height of source

. . . K27

3.0 PROGRAM USER INFORMATION

3.01 Input Data: Cont'd.

Card #	Column	Format	Name	Unit	Description
3	2-80	79H	ID		Users identification of problem
4	1-8	F8.1	QT1	cfs	Total gas flow rate at T1
4	9-16	F8.1	V	fps	Exit gas velocity
4	17-24	F8.0	T2	°F	Exit temperature of the gas
4	25-32	F8.0	T1	°F	Temperature at which the gas density equals that of the atmosphere
4	33-40	F8.2	Q	cfs	Contaminant gas flow rate
4	40-80	5F8.2	U(I)	fps	Wind velocity (maximum of 5)
5	1-80	10F8.0	D(J)	ft.	Downwind distance (maximum of 10)
6	1-80	10F8.0	DE(J)	ft.	Difference in elevations from corresponding downwind distance and base of source (maximum of 10)

3.02 Output

3.021 Explanation of Output

Calculated Output

Stability	Units	Symbol Used in Program
1-Extremely unstable	-	KSTAB
2-Moderately unstable	-	
3-Slightly unstable	-	
4-Neutral	-	
5-Slightly Stable	-	
6-Moderately Stable	-	
Thermal Rise	ft.	AHT
Velocity Rise	ft.	AHV
Effective stack height	ft.	ES(J)
Effective stack height at distance D(S)	ft.	ET(J)
Vertical spread	ft.	VSH
Lateral spread	°	SLS
Downwind concentration	ppm	CO(J)

. . . K28

3.03 No programmed stops

4.0 OPERATIONAL DETAILS

4.01 No sense switch settings

4.02 No operator instruction card

4.03 Program contains subroutine XXXX

. . . K29

```
.FLAG   JOB.GO,SP510
[illegible]
      DIMENSION U(10),B(10),X(26,6),Y(26,6),SLOP(6,26),[illegible]
     10),CO(10),XX(10),SGR(10),[illegible](10),ZZ(10)
      [illegible]
      READ(1,128)((SLOP(KSTAR,IZ),KSTAR=1,6),IZ=1,[illegible]
      READ(1,117)KA
  117 FORMAT(I3)
      XX(1)=1.0
      XX(2)=[illegible]
      XX(3)=[illegible]
      XX(4)=1[illegible].
      XX(5)=14.67
      XX(6)=2[illegible].
      XX(7)=[illegible].
      XX(8)=20.24
      XX(9)=[illegible]
      XX(10)=[illegible].
      ZZ(1)=.7292
      ZZ(2)=.7292
      ZZ(3)=.[illegible]
      ZZ(4)=.[illegible]
      ZZ(5)=.8020
      ZZ(6)=.9004
      ZZ(7)=1.0295
      ZZ(8)=1.7862
      ZZ(9)=2.[illegible]
      ZZ(10)=3.1[illegible]
      [illegible] I=1,[illegible]
      [illegible]
  126 [illegible]
      READ(1,[illegible])
  127 FORMAT(8(F6.0,F6.0))
      READ(1,118)[illegible]
  118 FORMAT([illegible])
      READ(1,119)(B(J),J=1,10)
  119 FORMAT([illegible])
```

```
     [illegible]
128 FORMAT(12F5.0)
102 FORMAT(80H
   1                                                  )
110 FORMAT(25H)            WIND VELOCITY ,F5.2,4H[illegible]
   1 SOURCE,F5.0,3HFT.)
111 FORMAT(25H0DISTANCE FROM SOURCE,FT.,10F9.0)
112 FORMAT(21H0EFF.STACK HEIGHT,FT.,4X,10F9.0)
113 FORMAT(19H0DIFF. IN ELEV. FT.,6X,10F9. )
114 FORMAT(18H0CONCENTRATION,PPM,7X,10F9.4)
115 FORMAT(61H1DEPARTMENT OF HEALTH, ENVIRONMENTAL HEA
   1ISION)
116 FORMAT(50H CALCULATION OF GROUND LEVEL CONCENTRATION [illegible]
   1D SOURCES, STACKS, PASQUILL METHOD)
150 FORMAT(42H0ATMOSPHERIC CONDITION,  STRONG I
151 FORMAT(44H0ATMOSPHERIC CONDITION,
152 FORMAT(42H0ATMOSPHERIC CONDITION,  SLIGHT INS LATI
153 FORMAT(52H0ATMOSPHERIC CONDITION,  HEAVY OVERCAST DAY [illegible])
154 FORMAT(79H0ATMOSPHERIC CONDITION,  THINLY OVERCAST, [illegible]
   1AN 4/8 LOW CLOUD, NIGHT)
155 FORMAT(54H0ATMOSPHERIC CONDITIONS, GREATER THAN 4/8 [illegible], NIG
208 FORMAT(1H0,6X,4HCT= ,F7.1,4X,4HVS= ,F5.1,4X,3HT= ,F5.[illegible]
   1 ,4X,[illegible])
    DO 997 KKK=KB,KC
    ISTAB=KKK
    WRITE(2,115)
    WRITE(2,116)
    WRITE(2,102)
    GO TO(440,441,442,443,444,445),ISTAB
440 WRITE(2,150)
    GO TO 450
441 WRITE(2,151)
    GO TO 450
442 WRITE(2,152)
    GO TO 450
443 WRITE(2,153)
    GO TO 450
444 WRITE(2,154)
    GO TO 450
445 WRITE(2,155)
450 CONTINUE
    DEL=T2-T1
    SQDV=SQRTF(DT*VS)
    DO 999 I=1,KWIN
    WRITE(2,110)U(I),[illegible]
    T1=T1+460.
    DO 998 J=1,KDIST
    DIST,KDIST TIMES
    CALCULATION  OF  VELOCITY AT
    IF(U(I)-[illegible])[illegible]
200 GO TO(300,301,301,302,3[illegible],3[illegible]),ISTAB
201 GO TO(301,301,302,302,304,3[illegible]),ISTAB
202 IF(U(I)-12.0)203,203,204
203 GO TO(301,302,302,302,303,304),ISTAB
204 IF(U(I)-20.0)203,205,205
205 GO TO(302,303,303,303,303,[illegible]),ISTAB
300 IF(J-1)3[illegible],3[illegible]0,360
350 WRITE(2,120)
360 KSTAB=1
    IF(D(J)-550.)15,15,16
```

K31

```
      IF(D(J)-X(II,KSTAR))404,405,406
  406 CONTINUE
      [illegible]
  404 VGH=Y(II-1,KSTAR)+(Y(II,KSTAR)-Y(I[illegible]
     Z(X(II,[illegible])-[illegible]
      [illegible]
  405 VGH=Y(II,KSTAR)
      [illegible]
      RETURN
      END

  600 183   650 202   700 218   750 235   800 253   850 [illegible]
  [illegible]
  1400 530  1500 580  1600 670  1650 700  1700 720  1750 [illegible]  1800 [illegible]
  1050 200  1200 270  1400 350  1500 318  1700 365  1800 415  [illegible]
  2500 500  2700 600  3000 715  3100 780  3300 860  3500 [illegible]
  41001180  43001300  45001365  47001450  4900[illegible]  51[illegible]
  55001800  57002000

                                 [illegible]
  7000 430  8000 460  9500 510 11000 560 12500 630 14[illegible]
 10500 350 [illegible]
 [illegible]
  7500 275  8500 305  9500 315 11000 345 12000 370 [illegible]
 30000 455 35000 555 40000 600 45000 675 60000 760 [illegible]
 [illegible]
  3450 101  4700 134  5700 14[illegible]  [illegible] 166  8000 190 [illegible]
 18700 260 24500 290 29000 314 34500 335 41500 360 [illegible]
 [illegible]0000 405120000 530140000 54[illegible]00 5[illegible]56000 6[illegible]
 8.  4.  20.  20.  15.  15.  20.  20.  15.  16.  7.   .
```

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APPENDIX C

COMPUTATIONAL EXAMPLE ILLUSTRATING METHOD OF FLARE STACK CALCULATIONS

Flaring is normally utilized during plant upset or other abnormal plant condition and is a convenient means of effectively reducing contaminant pollution to an acceptable level. The method of computing downwind pollutant concentrations from flares described in this paper was proposed by Professor Bouthillier and involves making a material and momentum balance around the flare.

The total amount of gas going to the flare and its constituents are estimated. The heating value of the flared gas is calculated and if less than 250 B.T.U./ft.^{3} then additional fuel (residue) gas must be added to bring the heating value up to this figure. Experience has shown that a minimum of 250 B.T.U./ft.^{3} should be maintained to reduce the possibility of flame failure and ensure successful flaring. A complete combustion balance on all materials is then performed and the heat capacities of the combustion products calculated. Twenty-five percent of the gross available heat is assumed to be lost due to radiation. Then the amount of heat available for heating the excess air is calculated. The heat available for this purpose is the difference between the 75 percent of the gross heat and the heat content of the combustion products which at 1800°F is 35.85 B.T.U./ft.^{3} referenced at 60°F. The total volume of air heated and waste gases can then be estimated.

EXAMPLE

The following is a detailed example of the method described above for the estimation of downwind ground level pollutant concentrations from flares.

Stack Height = 65 feet.

Stack diameter, top 6 inches, stack area 0.197 sq. ft.

Raw Gas Entering Stack

H_2S 1.20 cfs = 4,300 scfh = 384 lb./hr.

CO_2 1.20 cfs = 4,300 scfh = 496 lb./hr.

Residue gas CH_4 1.20 cfs = 4,300 scfh = 181 lb./hr.

12,900 scfh = 1,061 lb./hr.

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EXAMPLE: Cont'd.

Combustion Products

$$2H_2S + 3O_2 \;\rule{2cm}{0.4pt}\; 2H_2O + 2SO_2$$

$$CH_4 + 2O_2 \;\rule{2cm}{0.4pt}\; CO_2 + 2H_2O$$

Volumes in scfh

$$4{,}300\ H_2S + 6{,}450\ O_2 + 24{,}300\ N_2 \;\rule{1.5cm}{0.4pt}\; 4{,}300\ H_2O + 4{,}300\ SO_2 + 24{,}300\ N_2$$

$$4{,}300\ CO_2 \;\rule{1.5cm}{0.4pt}\; 4{,}300\ CO_2$$

$$4{,}300\ CH_4 + 8{,}600\ O_2 + 32{,}400\ N_2 \;\rule{1.5cm}{0.4pt}\; 4{,}300\ CO_2 + 8{,}600\ H_2O + 32{,}000\ N_2$$

Total Volumes scfh

$$4{,}300\ H_2S + 4{,}300\ CO_2 + 4{,}300\ CH_4 + 15{,}000\ O_2 + 56{,}700\ N_2$$

$$4{,}300\ SO_2 + 8{,}600\ CO_2 + 12{,}900\ H_2O + 56{,}700\ N_2$$

Heat Released

H_2S . . . . . 4,300 scfh x .647 M B.T.U./scf = 2,782 M B.T.U./hr.

CH_4 . . . . . 4,300 scfh x 1.013 M B.T.U./scf = 4,356 M B.T.U./hr.

Total 7,138 M B.T.U./hr.

$$\text{Average Heat Content of Gases} = \frac{7{,}138{,}000\ \text{B.T.U./hr.}}{12{,}900\ \text{scfh}}$$

$$= 553\ \text{B.T.U./scf.}$$

Heat Content of Combustion Products, assuming ave. of flame temp. of 1800°F.

Gas	VOLUME scfh	lb./hr.	ENTHALPY B.T.U./lb. at 1800°F	M B.T.U./hr.
SO_2	4,300	723	320	231
CO_2	8,600	995	496	494
H_2O	12,900	610	901	550
N_2	56,700	4170	467	1947
	82,500	6,498	—	3,222

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EXAMPLE: Cont'd.

Assuming 25 percent of the gross available heat is lost due to radiation,

$$\text{Heat to excess air} = 0.75\ (7{,}138\ \text{M B.T.U./hr} - 3{,}222\ \text{M B.T.U./hr})$$

$$= 2{,}937{,}000\ \text{B.T.U./hr.}$$

Excess Air Warmed to 1800°F

$$\frac{2{,}937{,}000\ \text{B.T.U./hr.}}{35.85\ \text{B.T.U./ft.}^3} = 81{,}925\ \text{scfh} = 6{,}262\ \text{lb./hr.}$$

Velocity in Tip

$$\text{Velocity in tip} = \frac{12{,}900\ \text{scfh}}{0.197\ \text{sq. ft. } (3600)} = 18.2\ \text{fps}$$

Momentum of raw gas = Momentum of combustible products and excess air.

$$V_s = \frac{1{,}061\ \text{lb./hr.}(18.2)\ \text{fps}}{6{,}498\ \text{lb./hr.} + 6{,}262\ \text{lb./hr.}} = 1.51\ \text{fps}$$

Combustion products plus excess air at 60°F

$$= 82{,}500 + 81{,}925 = 164{,}425\ \text{scfh}$$

Q_{T_1} = Combustion products plus excess air at 70°F

= 46.5 cfs

$\triangle$ = 1800° - 70° = 1730°F (stack minus ambient temperature)

Once Q_{T_1} and Vs are obtained the downwind pollutant concentration can be calcalculated by using suitable thermal rise, velocity rise, and diffusion equations. It is considered that the thermal rise of the waste gases will not be as large as that resulting from the incineration of a similar amount of gas in an incinerator and its release from an incinerator stack. To compensate for this a factor of only 0.5 of the calculated thermal rise of the gases is used in the compution of the effective height of the flare stack.

$$He = hs + 0.50\ (hv + ht)$$

where He = effective stack height, ft.
hs = flare stack height, ft.
hv = velocity rise, ft.
ht = thermal rise, ft.

A momentum equation is used to estimate the velocity rise. Since the volume of heated air and combustion products is in the order of twenty times that of the raw gases the velocity rise will be quite low, however the velocity of the gas should not be estimated at less than 1 fps.

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APPENDIX D

PROGRAM NO. SH 508

PROGRAM TITLE: DEPARTMENT OF HEALTH

STACK CALCULATIONS - CALCULATION OF GROUND LEVEL CONCENTRATIONS FROM FLARES

DATE: June 1965

PROGRAMMER: E. Kupchanko

1.0 SCOPE OF PROGRAM

1.01 Purpose

1.011 Problem Description

This program was designed to calculate the maximum pollutant gas concentration and the distance to the maximum for varying stack heights, and wind velocities, using contaminate flow to the flare and fuel gas rates.

1.012 The advantages of this program are that it can be set up quickly (3 cards for each set of conditions).

1.02 Method

1.021 Method of Solution Programmed

A material balance is made around the flare. The heating value of flared gas is calculated. A complete combustion balance on all materials is performed and the heat capacity of the combustion products is obtained. Twenty-five per cent of the gross available heat is assumed to be lost due to radiation. Next the amount of heating excess air is calculated. The available heat for this purpose is the difference between seventy-five per cent of the gross heat and the heat content of the products of combustion. The total volume of air and waste gases can thus be obtained. The maximum pollutant gas concentration at ground level, and the distance from the stack at which it occurs is calculated using the Sutton equation with the Lowry modification, (1), and the Bosanquet - Pearson method. (2).

. . . K38

$$Co\ Max\ (ppm) = 2.35 \times 10^5 \left(\frac{Q}{He^2} \cdot \frac{Am}{U} \right) \qquad (1)$$

Where He = equivalent stack height defined by (2)

$$He = h_s + .50\ (h_v + h_t)$$

It is not considered that the thermal rise obtained by flaring will be as large as that resulting from burning an equal amount of gas in an incinerator and accompanying stack. To compensate for this a factor of only 0.5 of the calculated thermal rise of the gases is used in the computation of the effective height of the flare stack.

Where h_s = stack height (ft.)

h_v = velocity rise; distance the gas rises in the atmosphere because of its momentum

h_t = thermal rise; the distance the gas rises in the atmosphere because of its elevated temperature

Q = contaminant gas flow rate at ambient conditions

U = wind velocity (ft./sec.)

Am = a function of wind velocity

1.022 Calculation of Velocity Rise, h_v

$$h_v = \left(\frac{4.77}{1 + .43\ U/V_s} \right) \cdot \left(\frac{\sqrt{Qtl \cdot Vs}}{U} \right)$$

Where Qtl = total gas flow rate from stack ft.^{3}/sec. at ambient conditions (i.e. 70°F and 14.7 psi)

Vs = velocity of gas in stack, ft./sec.

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1.023 Calculation of Thermal Rise, h_t (Case No. 1)

$$h_t = .387\ Qtl\ \Delta\ Z/U^3$$

Where Δ = difference T°F. Between air and stack gas temperatures

$$Z = \ln J^2 + \frac{2}{J} - 2$$

$$J = \frac{U^2}{\sqrt{Qtl Vs}} \left(.43 \sqrt{\frac{T1}{gG}} - .28 \frac{Vs}{g} \frac{T1}{\Delta} \right) +1.$$

g = acceleration due to gravity 32.17 ft./sec.^{2}

G = a function of wind velocity

T1 = temperature at which stack gas equals that of atmosphere (°F)

T2 = stack gas temperature (°F)

1.024 Calculation of Termal Rise, h_t (Case No. 2)

$$h_t = .387\ Qtl\ \Delta\ Z/U_3$$

$$X = \frac{xU}{3.57 \sqrt{Qtl\ .\ VS}}$$

Where Δ = difference T°F between air and stack gas temperatures

A relationship between X and Z is shown on a graph Bosanquet Thermal rise parameters for air, adiabatic atmosphere (Magill, Holden, Ackley, Air Pollution Handbook).

1.025 Calculation of Distance to Maximum Concentration Cases 1 and 2

Case 1 X = 20 He

Case 2 X = 10 He

Where X = distance from stack at which maximum pollutant concentration occurs

He = effective stack height

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2.0 LIMITATIONS

2.01 For any one set of problems the maximum number of stack heights is 6, maximum number of wind velocities is 10; no more than 99 sets of conditions may be solved at one time. Wind velocities and diffusion parameters are fixed although may be changed internally in the program.

3.0 PROGRAM USER INFORMATION

3.01 Input Data

Card No.	Column	Format	Name	Unit Description
1	1 - 2	2 I	KA	number of sets of data
1	3 - 4	2 I	KZ	number of stack heights
2	2 - 80	79 H	ID	user's indentification of problem
3	1 - 8	F8.0	Q	quantity of gas to flare including fuel (cfh)
3	9 - 14	F6.4	T	diameter of flare (ft.)
3	15 - 20	F6.4	C_1	decimal per cent of C1 constituent in gas to flare
3	21 - 26	F6.4	C_2	decimal per cent of C_2 constituent in gas to flare
3	27 - 32	F6.4	C_3	Decimal per cent of C_3 constituent in gas to flare
3	33 - 38	F6.4	C_4	decimal per cent of C_4 constituent in gas to flare
3	39 - 44	F6.4	C_5	decimal per cent of C_5 constituent in gas to flare
3	45 - 50	F6.4	A_2	decimal per cent of N_2 constituent in gas to flare

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Card No.	Column	Format	Name	Unit Description
3	51 - 56	F6.4	H_2S	decimal per cent of H_2S constituent in gas to flare
3	57 - 62	F6.4	SO_2	Decimal per cent of SO_2 contituent in gas to flare
3	63 - 68	F6.4	O_2	decimal per cent of O_2 constituent in gas to flare
3	69 - 74	F6.4	CO_2	decimal per cent of CO_2 constituent in gas to flare
4	1 - 7	F7.0	T_2 °F	temperature of flare gases (usually 1800° F)
4	8 - 14	F7.0	T_1 °F	temperature at which the density of the products of combustion at 70° F equals that of atmosphere (usually 70° F)
4	15 - 56	F7.0	SH (J) ft.	Jth stack height (no more than 6)

ID Card must always preceed data card

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[illegible]

. . . . K44

```
      [illegible]
      U(5)=1[illegible]
      [illegible]
      [illegible]
      U(7)=[illegible]
      U(8)=[illegible]
      U(9)=[illegible]
      U(10)=[illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      FP(10)=[illegible]
  106 FORMAT(8F7.0)
  [illegible]
  [illegible]
  [illegible]
  [illegible]
  [illegible]
  [illegible]
  [illegible]        [illegible] LINE [illegible]
     [illegible]
  [illegible]        VEL CONCENTRATION [illegible]
  [illegible]        [illegible] CONDITIONS [illegible]
  [illegible]        [illegible](4X,F[illegible]))
  [illegible]
  [illegible]
  [illegible]
     1[illegible],4X,5H[illegible]
  209 FORMAT(53H    CASE #[illegible] CALCULATIONS INVALID BELOW [illegible]
     1[illegible]
  211 FORMAT(82H
     1
      WRITE([illegible])L
      WRITE OUTPUT TAPE 2,2[illegible],(U(I),I=1,10)
      DEL=T2-T1
      T1=T1+[illegible].
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      SQR(I[illegible])
      [illegible]V(I,[illegible])*SQGV/U(I)
      [illegible]=(U(I)**2/SQGV)*(SQR(I)-(.28*VS*T1/(32.17*DEL)))+1.
      [illegible]
```

K45

```
      [illegible]
      [illegible](I)= [illegible](I)+[illegible](I,J)),[illegible](J))
      [illegible]AY(I)=[illegible](I)/[illegible](I)[illegible]
[illegible] P(I,J)=[illegible](I)
      WRITE OUTPUT TAPE 2,111,([illegible](I),I=1,10)
      WRITE(2,112)([illegible]V(I,J),I=1,10)
      WRITE(2,113)([illegible](I),I=1,10)
      WRITE(2,114)(CMAX(I),I=1,10)
      WRITE(2,115)(P(I,J),I=1,10)
[illegible] CONTINUE
      WRITE(2,226)L
      WRITE OUTPUT TAPE 2,[illegible],([illegible](I),I=1,10)
      DO [illegible] J=1,27
      WRITE OUTPUT TAPE 2,[illegible],[illegible](J)
      DO 71 I=1,10
      [illegible]=P(I,J)
[illegible] XP=YAMU(I)/(2.57[illegible])
      IF(XP-[illegible])[illegible],[illegible],[illegible]
[illegible] ZP=XP/(2.17[illegible])
      GO TO [illegible]
[illegible] [illegible]
[illegible] CONTINUE
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
[illegible] [illegible]
      [illegible]
[illegible] [illegible]
      [illegible]
      [illegible]
[illegible] [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
[illegible] CONTINUE
      [illegible]
      [illegible]
      [illegible]
[illegible] CONTINUE
      [illegible]
      [illegible]
      [illegible]
[illegible] CONTINUE
      END
[illegible]
```

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PROGRAM: SH507

PROGRAM TITLE: Department of Health
Flare Calculations
Pasquill Method

DATE: April 1968

BY: P. M. Ullman

1.0 SCOPE OF PROGRAM

1.01 Purpose

1.011 Problem Description

This program was designed to calculate the estimation of downwind concentrations of air borne material. The method proposed gives concentrations specifically in terms of the vertical spread of the plume and the practical problem is thus transformed into making the best possible estimates of these quantities.

1.012 The program uses tabular data empirically derived together with theoretical equations.

1.02 Method

1.021 Method of Solution Programmed

The program calculates the distribution of concentration downwind of a source using the method as outlined in a paper by Pasquill. (1)

$$Co\ (ppm) = \frac{1.68 \times 10^8 \times Q}{u\ d\ \theta\ h}$$

where Q = contaminant emission rate at ambient conditions

u = wind velocity (fps)

d = lateral distance from the source (ft.)

θ = lateral spread

h = vertical spread (ft.)

The magnitude of h initially increases with the distance d from the source and varies according to the rapidity with which the vertical mixing occurs in the atmosphere.

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1.022 Key to Stability Factors

ISTAB	1	2	3	4	5	6
Surface Wind Speed fps	Strong	Insolation Moderate	Slight	Heavily Overcast day or night	Thinly Overcast or >4/8 Low Cloud Night	<3/8 Cloud Night
fps	KSTAB	KSTAB	KSTAB	KSTAB	KSTAB	KSTAB
< 6.5	1	1-2	2	4	-	-
6.5	1-2	2	3	4	5	6
13	2	2-3	3	4	4	5
20	3	3-4	4	4	4	4
> 20	3	4	4	4	4	4
	unstable conditions			neutral	stable conditions	

1.023 Estimation of the Lateral Spread θ

The values of θ for the two extreme distances, 330 feet and 330,000 were extrapolated from the various observations below.

Stability Category (ISTAB)	d = 330 feet	d = 330,000 feet
1	50°	25°
2	40°	20°
3	30°	15°
4	20°	10°
5	15°	7°
6	10°	5°

1.024 Allowance for Elevation of Source

If the source is elevated the concentrations at ground level will be reduced at the shorter distances but will tend more closely to the ground source values as the distance is increased. A correction factor is then used to multiply the derived values of Co.

$$F = \frac{1}{e^{(2.303\ H^2/h^2)}}$$

1.024 Allowance for Elevation of Source - Cont'd.

where F = correction factor

H = effective height of source

h = vertical spread

1.025 Thermal Rise

For strong, moderate, and slight insolation the thermal rise is obtained by the following equations for unstable conditions.

$$h_t = .387 \; Qtl \, \Delta Z \; / \; u^3$$

$$X = \frac{xu}{3.57 \; Qtl \; V_s}$$

where Δ = difference (T°F) between air and flare gas temperatures

Qtl = total gas flow rate from flare (ft.^{3}/sec.) at ambient air conditions (70°F)

V_s = velocity of gas in flare (ft./sec.)

x = distance to point of maximum pollution

The relationship between x and Z is shown on the graph Bosanquet thermal rise parameters for an adiabatic atmosphere.

For heavy overcast day or night, thinly overcastor 4/8 low cloud, and 3/8 cloud night thermal rise is obtained by the following equations for stable conditions.

$$h_t = .387 \; QTl \, \Delta \, Z \; / \; u^3$$

where Δ = difference (T°F) between air and flare gas temperatures

QTl = total gas flow rate from flare (ft.^{3}/sec.) at ambient air conditions (70°F)

$$Z = \ln J^2 + \frac{2}{J} - 2$$

$$J = \frac{u^2}{Qtl \; Vs} \left(.43 \sqrt{\frac{Tl}{gG}} - .28 \frac{Vs}{g} \cdot \frac{Tl}{} \right) + 1$$

1.025 Thermal Rise - Cont'd.

where g = acceleration due to gravity 32.17 ft./sec.^{2}

G = Gm, a function of wind velocity

$T1$ = temperature at which flare gas density equals that of atmosphere (°F)

u = wind velocity (fps)

1.026 Velocity Rise

$$hv = \frac{4.77}{1 + .43\, u/V_s} \quad \frac{Qtl \,.\, Vs}{u}$$

where Qtl = total flow rate from flare (ft.^{3}/sec.) at ambient conditions

Vs = velocity of gas in flare (ft./sec.)

u = wind velocity (ft./sec.)

1.027 Effective Stack Height

$$H = hs + .50\, (hv + h_t)$$

2.0 LIMITATIONS

2.01 For any one set of problems the maximum number of wind velocities is 5; the maximum distances from the source is ten. The two extreme distances from the source are 330 feet and 330,000 feet.

3.0 PROGRAM USER INFORMATION

3.01 Input Data

NOTE: Control Cards Each Set of Data, 2 and 3.

Card #	Column	Format	Name	Unit	Description
1	1-3	I3	KA		Number of Sets of data
2	1-3	I3	Kwind		Number of wind speeds (maximum of 5)
2	4-6	I3	Kdist		Number of distances (maximum of 10)
2	7-9	I3	KB		Lower stability number

. . . K5

3.0 PROGRAM USER INFORMATION

3.01 Input Data - Cont'd.

Card #	Column	Format	Name	Unit	Description
2	10-12	I3	KC		Higher Stability number (KC KB)
2	13-18	F6.0	SH	ft.	Height of source
3	2-80	79H	ID		User identification of problem
4	1-8	F8.0	Q	cfh	Quantity and gas to flare includes fuel
4	9-16	F8.4	T	ft.	Diameter of flare
4	17-24	F8.0	T2	°F	Exit tip temperature (1800°F)
4	25-32	F8.0	T1	°F	Temperature at which the density of the products of combustion at 70°F equals that at atmosphere (70°F)
4	33-	5F8.2	U(I)=I=1,5	FPS	5 wind speeds
5	1-8	10F8.4	C1	decimal %	Decimal per cent of C1 constituent in gas to flare
5	9-16		C2		Decimal per cent of C2 constituent in gas to flare
5	17-24		C3		Decimal per cent of C3 constituent in gas to flare
5	25-32		C4		Decimal per cent of C4 constituent in gas to flare
5	33-40		C5		Decimal per cent of C5 constituent in gas to flare
5	41-48		A2		Decimal per cent of N_2 constituent in gas to flare
5	49-56		H_2S		Decimal per cent of H_2S constituent in gas to flare
5	57-64		SO_2		Decimal per cent of SO_2 constituent in gas to flare
5	65-72		O_2		Decimal per cent of O_2 constituent in gas to flare
5	73-80		CO_2		Decimal per cent of CO_2 constituent in gas to flare

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3.0 PROGRAM USER INFORMATION

3.01 Input Data - Cont'd.

Card #	Column	Format	Name	Unit	Description
6	1-80	10F8.0	D(J)	ft.	Downwind distance
7	1-80	10F8.0	DE(J)	ft.	Difference in Elevation

3.02 Output

3.021 Explanation of Output

Calculated Output

Stability	Units	Symbol Used in Program
1-Extremely unstable	-	
2-Moderately unstable	-	
3-Slightly unstable	-	KSTAB
4-Neutral	-	
5-Slightly stable	-	
6-Moderately stable	-	
Thermal Rise	ft.	AHT
Velocity Rise	ft.	AHV
Effective Stack Height	ft.	ES(J)
Effective Stack Height at Distance D(S)	ft.	ET(J)
Vertical Spread	ft.	VSH
Lateral Spread	0	SLS
Downwind Concentration	ppm	CO(J)

3.03 No programmed stops

4.0 OPERATIONAL DETAILS

4.01 No sense switch settings

4.02 No operator instruction card

4.03 Program contains subroutine XXXX

```
--
.FLAG  JOR.SH50/
.[illegible]
      DIMENSION U(10),D(10),X(25,6),Y(25,6),SLSZ(6,2),[illegible](10),[illegible]
     1[illegible]),C[illegible](10),XX(10),[illegible](10),[illegible](10),ZZ(10)
      READ(1,127)((X(II,KSTAR),Y(II,KSTAR),II=1,25),KSTAR=1,6)
      READ(1,128)((SLSZ(KSTAR,IZ),KSTAR=1,6),IZ=1,2)
      READ(1,117)KA
  117 FORMAT(I3)
      XX(1)=1.0
      XX(2)=5.
      XX(3)=7.34
      XX(4)=10.
      XX(5)=14.67
      XX(6)=2[illegible].
      XX(7)=[illegible].
      XX(8)=[illegible].34
      XX(9)=[illegible].67
      XX(10)=44.
      ZZ(1)=.[illegible]
      ZZ(2)=.[illegible]
      ZZ(3)=.[illegible]
      ZZ(4)=.1292
      ZZ(5)=.[illegible]
      ZZ(6)=.9904
      ZZ(7)=1.0295
      ZZ(8)=1.7862
      ZZ(9)=2.3964
      ZZ(10)=[illegible].10[illegible]
      DO 1000 L=1,KA
      [illegible]=[illegible].
      [illegible]=[illegible].
      VC[illegible]=0.
      V[illegible]=[illegible].
      V[illegible]=[illegible].
      V[illegible]=[illegible].
      TV[illegible]L=[illegible].
      T[illegible]=[illegible].
      [illegible]C=0.
      TH=[illegible].
      T[illegible]=[illegible].
C     CALCULATION OF GROUND LEVEL CONCENTRATIONS [illegible]
C     USING PASQUILL METHOD, REVISED, JAN.,1960, P.[illegible]
      READ(1,126)KWIND,KDIST,KB,KC,SH
  126 FORMAT(4I3,F6.0)
      READ(1,102)
  127 FORMAT(8(F6.0,F4.0))
      [illegible](1,118)[illegible],[illegible],[illegible],[illegible],([illegible](I),I=1,[illegible])
  118 FORMAT(F8.0,F8.4,2F8.0,[illegible]F8.2)
      READ(1,103)C1,C2,[illegible],[illegible],[illegible],A2,B2,[illegible]2,D2,C0[illegible]
  103 FORMAT(10F8.4)
      READ(1,119)(D(J),J=1,10)
  119 FORMAT(10F8.0)
      READ(1,119)(DF(J),J=1,10)
      [illegible]=[illegible].
      [illegible]=[illegible].
      VC1=[illegible]1
      VC2=Q*C2
```

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```
      VC3=0*C3
      VC4=0*C4
      [illegible]
      VH2S=0*H2S
      [illegible]
      VO2=0*O2
      [illegible]
      VSO2=0*SO2
      TVOP=0
      HR=1013.*VC1+1792.*VC2+2590.*VC3+3370.*VC4+4016.*VC5+[illegible]
      HOC=HR/TVOP
      IF(HOC-250.)3,4,4
      WRITE(2,5)HOC
5     FORMAT(26HOTHE [illegible]
     1INSUFFICIENT FOR ADEQUATE INCINERATION)
      GO TO 996
      CONTINUE
      WC1=VC1*.0424
      WC2=VC2*.[illegible]
      WC3=VC3*.1196
      WC4=VC4*.15[illegible]
      WC5=VC5*.1[illegible]
      WO2=VO2*.0[illegible]
      WN2=VN2*.0744
      WH2S=VH2S*.0[illegible]1
      WCO2=VCO2*.1170
      [illegible]
      [illegible]
      [illegible]
      VH2O=2.*VC1+3.*VC2+4.*VC3+5.*VC4+6.*VC5+VH2S+V[illegible]
      [illegible]
      [illegible]2=V[illegible]2/3600.
      V[illegible]=2.*VC1+3.5*VC2+5.*VC3+6.5*VC4+8.*VC5+1.5*VH2S-[illegible]
      [illegible]
      [illegible]=[illegible]+V[illegible]+V[illegible]+V[illegible]
      [illegible].0744
      [illegible]*.[illegible]
      [illegible]2=V[illegible]*.1170
      [illegible]2=VSO2*.1733
      T[illegible]=[illegible]O2+WH2O+WSO2+WN2
      [illegible]
      TH=(HR-HC)*.75
      [illegible]
      VEL=TVOP/(3600.*3.1415927*T*T/4.)
      [illegible]=(T[illegible]+V[illegible])/3600.
      [illegible]
      [illegible]
      I[illegible](V[illegible]-1.[illegible]7,[illegible]
      V[illegible]=1.0
      CONTINUE
      [illegible]
8     FORMAT(12F5.0)
2     FORMAT(80H
     1
0     FORMAT(25H0           WIND VELOCITY ,F5.2,4HFPS.,6X,[illegible]
     1 [illegible],F5.0,3HFT.)
1     FORMAT(25H0DISTANCE FROM SOURCE FT.,10F9.0)
2     FORMAT(21H0EFF.STACK HEIGHT,FT.,4X,10F9.0)
3     FORMAT(19H0DIFF. IN ELEV. FT.,6X,10F9.0)
4     [illegible]CONCENTRATION,PP[illegible],[illegible]X,10F9.4)
```

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```
115 FORMAT(61H1DEPARTMENT OF [illegible] ENVIRONMENT
   1[illegible])
 116 FORMAT(50H CALCULATION OF GROUND LEVEL CONCENTR
   1ON SOURCE , FLARE , PASQUILL METHOD)
150 FORMAT(42H0ATMOSPHERIC CONDITION, STRONG INSOLATION)
151 FORMAT(44H0ATMOSPHERIC CONDITION, MODERATE INSOLATION)
152 FORMAT(42H0ATMOSPHERIC CONDITION, SLIGHT INSOLATION)
153 FORMAT(52H0ATMOSPHERIC CONDITION, HEAVY [illegible]
154 FORMAT(79H0ATMOSPHERIC CONDITION, THINLY OVERCAST, [illegible]
   1AN 4/8 LOW CLOUD, NIGHT)
155 FORMAT(54H0ATMOSPHERIC CONDITIONS, GREATER THAN 3/8 [illegible]
208 FORMAT(1H0,6X,4HDT1 ,F7.1,4X,3HVS ,F5.1,4X,5HT2 ,F5.[illegible]
   1 ,4X,[illegible] ,F6.2)
    DO 907 KSK=KB,KC
    ISTAB=KSK
    WRITE(2,115)
    WRITE(2,116)
    WRITE(2,1[illegible]2)
    GO TO(440,441,442,443,444,445),ISTAB
440 WRITE(2,150)
    GO TO 450
441 WRITE(2,151)
    GO TO 450
442 WRITE(2,152)
    GO TO 450
443 WRITE(2,153)
    GO TO 450
444 WRITE(2,154)
    GO TO 450
445 WRITE(2,155)
450 CONTINUE
    DEL=T2-T1
    SQQV=SQRTF(QT1*VS)
    DO 906 J=1,[illegible]
    WRITE(2,110)D(J),[illegible]
    T1=T1+460.
    DO 908 J=1,KDIST
C   DIST,KDIST TIM
C   CALCULATION OF VELOCITY RISE
    IF(U(I)-6.0)[illegible]
200 GO TO(300,301,301,[illegible]),ISTAB
201 GO TO(301,301,[illegible]),ISTAB
202 IF(U(I)-13.0)203,203,204
203 GO TO(301,302,302,303,303,304),I[illegible]
204 IF(U(I)-20.0)203,205,205
205 GO TO(302,302,302,303,303,303),ISTAB
300 IF(J-1)250,250,360
250 WRITE(2,120)
360 [illegible]
    IF(D(J)-550.)15,15,16
 15 VSH=D(J)**.0093/1.636
    GO TO 400
 16 IF(D(J)-[illegible]
207 CALL XXXX (D,X,ISTAB,VSH,Y,SL5,SLS7,J)
    GO TO 400
218 IF(D(J)-3650.)209,209,210
209 VSH=.001254*D(J)**2-[illegible].668*D(J)+[illegible]384.5
    GO TO 400
210 VSH=6700.
    GO TO 400
```

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```
 11  IF(J-1)[illegible]
 51  [illegible]
 61 KSTAR=2
     IF(D(J)-1300.)18,18,19
 18  VSH=D(J)**.[illegible]/[illegible].[illegible]
     GO TO 400
 19  IF(D(J)-[illegible].)2[illegible],[illegible],[illegible]
 20 CALL XXXX (D,X,K TAR,VSH,T,[illegible]L[illegible],[illegible]L[illegible],J)
     GO TO 400
 21  IF(D(J)-[illegible].)22,2[illegible],[illegible]
 22. VSH=.000060*D(J)**2-.[illegible](J)+1[illegible].
     GO TO 400
 23  VSH=[illegible].
     GO TO 400
302 IF(J-1)352,352,362
352 WRITE(2,122)
362 KSTAR=3
     IF(D(J)-63000.)25,25,26
 25 VSH=D(J)**.8877/3.175
     GO TO 400
 26 VSH=6700.
     GO TO 400
303 IF(J-1)353,353,363
353 WRITE(2,123)
363 KSTAR=4
     IF(D(J)-4000.)30,30,31
 30 VSH=D(J)**.8410/3.820
     GO TO 400
 31  IF(D(J)-[illegible].)[illegible]
 4  CALL XXXX ([illegible],J)
     GO TO 400
 5   VSH=-.[illegible]*D(J)[illegible]+.[illegible](J)+[illegible].
     GO TO 400
304 IF(J-1)354,354,364
354 WRITE(2,124)
364 KSTAR=5
     IF(D(J)-3000.)35,35,36
 35 VSH=D(J)**.8020/4.093
     GO TO 400
 36 CALL XXXX (D,X,K TAR,V[illegible]H,T,[illegible]L[illegible],[illegible]L[illegible]Z,J)
     GO TO 400
305 IF(J-1)3[illegible]
355 WRITE(2,125)
365 KSTAR=6
     IF(D(J)-[illegible].)[illegible],4[illegible],[illegible]
 40 VSH=D(J)**.[illegible]0/6.06[illegible]
     GO TO 400
 41 CALL XXXX ([illegible],J)
 00 CONTINUE
     [illegible]
     IF([illegible])[illegible]
 10 IF(D(J)-20.)12,[illegible]
 12 Z=D(J)/(2.1/2+.[illegible]*D(J))
     GO TO 14
 13 Z=(L[illegible](D(J))-.[illegible])/.[illegible]
     GO TO 14
     STABLE  CONDITIONS
 11 CONTINUE
 01 CONTINUE
     DO 5[illegible]6 KZ=1,10
```

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```
      IF(U(I)-XX(KZ))504.505.506
  506 CONTINUE
      GO TO 601
  504 SQ(I)=ZZ(KZ-1)+(ZZ(KZ)-ZZ(KZ-1))*(U(I)-XX(KZ-1))/(
      GO TO 508
  505 SQ(I)=ZZ(KZ)
  508 CONTINUE
       QR(I)=SQ(I)*SQRTF(TT)
      AJ=(U(I)**2/32.*V) [illegible]
      Z=LOGF(AJ*AJ)+(2./AJ)-2.
   14 AHI=6.37+2.1*QI [illegible] U(I)**2)
      SLS=(SLSZ(KSTAR.1)-SLSZ(KSTAR.2))*(330000.-D(J))/32 [illegible]
     1R.2)
      FS(J)=.50*(AHI+ADV)+SLS
      IF(FS(J)-6500.)786.785.785
  786 FS(J)=6500.
  785 CONTINUE
  120 FORMAT(19H0EXTREMELY UNSTABLE)
  121 FORMAT(20H0MODERATELY UNSTABLE)
  122 FORMAT(18H0SLIGHTLY UNSTABLE)
  123 FORMAT(9H0NEUTRAL)
  124 FORMAT(16H0SLIGHTLY STABLE)
  125 FORMAT(18H0MODERATELY STABLE)
      FT(J)=FS(J)-H(J)
      IF(FT(J))51.50.51
   50 FSS=0.
      FT(J)=0.
      CO(J)=1.68*10.**8*QW/(U(I)*D(J)*SLS*VSH)
      GO TO 998
   51 FSS=FT(J)**2/VSH**2
      IF(FSS-[illegible].)53.53.52
   52 CO(J)=0.00
      GO TO 998
   53 CO(J)=(1./EXPF(2.303*FSS))*1.68*10.**8*QW/(U(I)*D(J) [illegible]
  998 CONTINUE
      T1=T1-460.
      WRITE(2.111)(D(J).J=1.10)
      WRITE(2.112)(FT(J).J=1.10)
      WRITE(2.113)(DE(J).J=1.10)
      WRITE(2.114)(CO(J).J=1.10)
  999 CONTINUE
      WRITE(2.208)QT1.VS.T2.T1.QSO2
  997 CONTINUE
  996 CONTINUE
 1000 CONTINUE
      END
.FLAG FORTRAN.XXXX
      SUBROUTINE XXXX (D.X.KSTAR.VSH.Y.SLS.SLSZ.J)
      DIMENSION D(10).X(25.6).Y(25.6).SLSZ(6.2)
  401 CONTINUE
      DO 406 II=1.25
      IF(D(J)-X(II.KSTAR))404.405.406
  406 CONTINUE
      GO TO 401
  404 VSH=Y(II-1.KSTAR)+(Y(II.KSTAR)-Y(II-1.KSTAR))*(D(J)-X(II-1.KSTAR))
     1/(X(II.KSTAR)-X(II-1.KSTAR))
      GO TO 408
  405 VSH=Y(II.KSTAR)
  408 CONTINUE
      RETURN
```

```
[illegible]
[illegible]
60 182   650 202   700 [illegible]
225   1000 245   1100 [illegible]   1100 [illegible]   [illegible]
1400 5[illegible]   1500 600   1600 670   1650 700   1700 [illegible]
[illegible]   1200 270   [illegible]   1650 700   1700 [illegible]
[illegible]
[illegible]
[illegible]

000.420   8000 460   9500 510 11000 560 12500 610 [illegible]
500 750 20000 700 24000 870 27000 950 29000 970 [illegible]
0001220 400001200 50000 1330 [illegible]
500 275   8500 205   9500 31[illegible] 11 00 44[illegible] 13000 [illegible]
000 656 22000 696 25000 [illegible]
000102 [illegible]
450 101   4700 124   5700 141   7700 166   8[illegible]
100 262 24500 292 28200 314 34000 33[illegible] 41500 [illegible]
00 40[illegible]   [illegible] 72266000 [illegible]
40.   30.   20.   15.   10.   25.   20.   15.   10.   [illegible].   [illegible].
```

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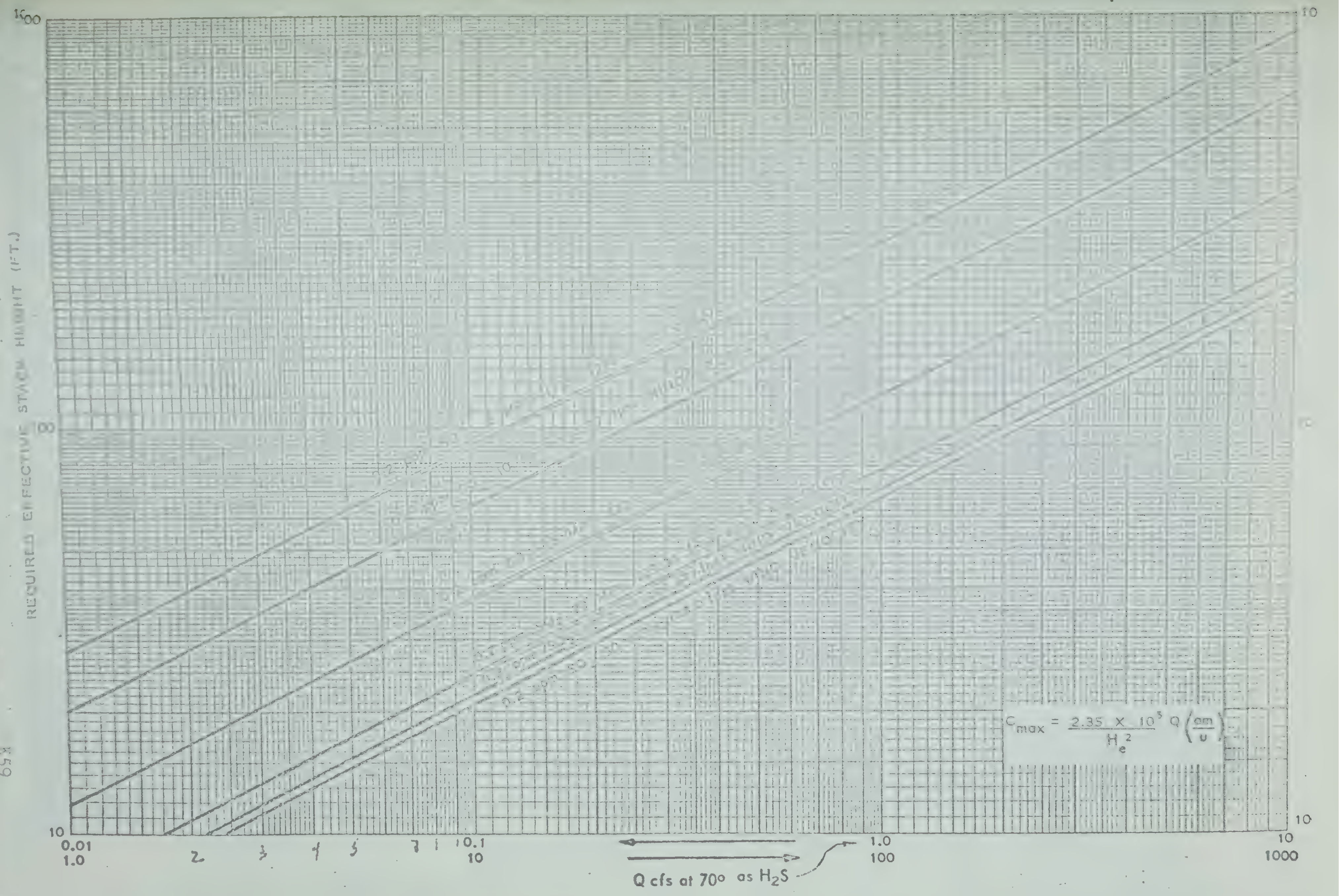
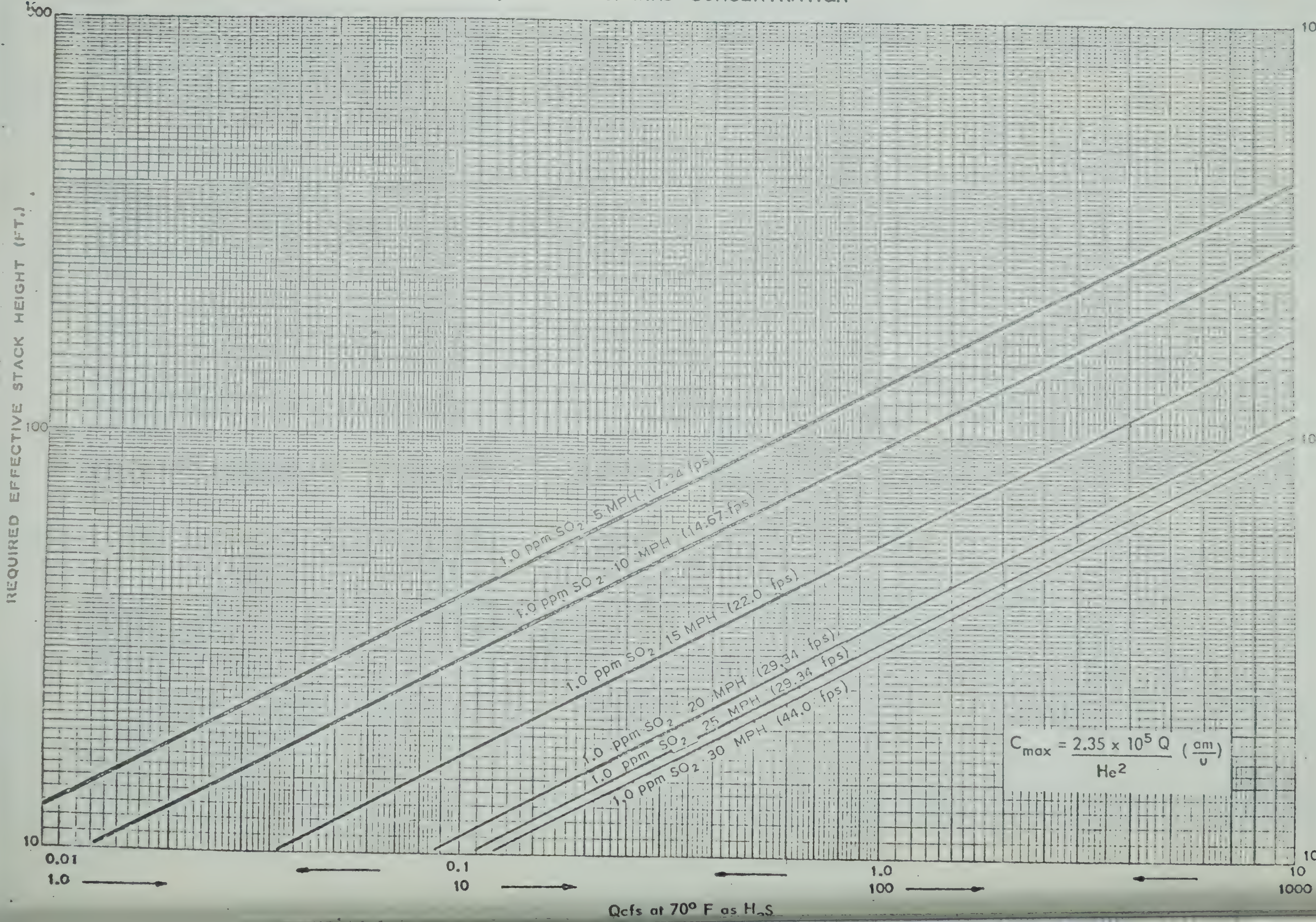
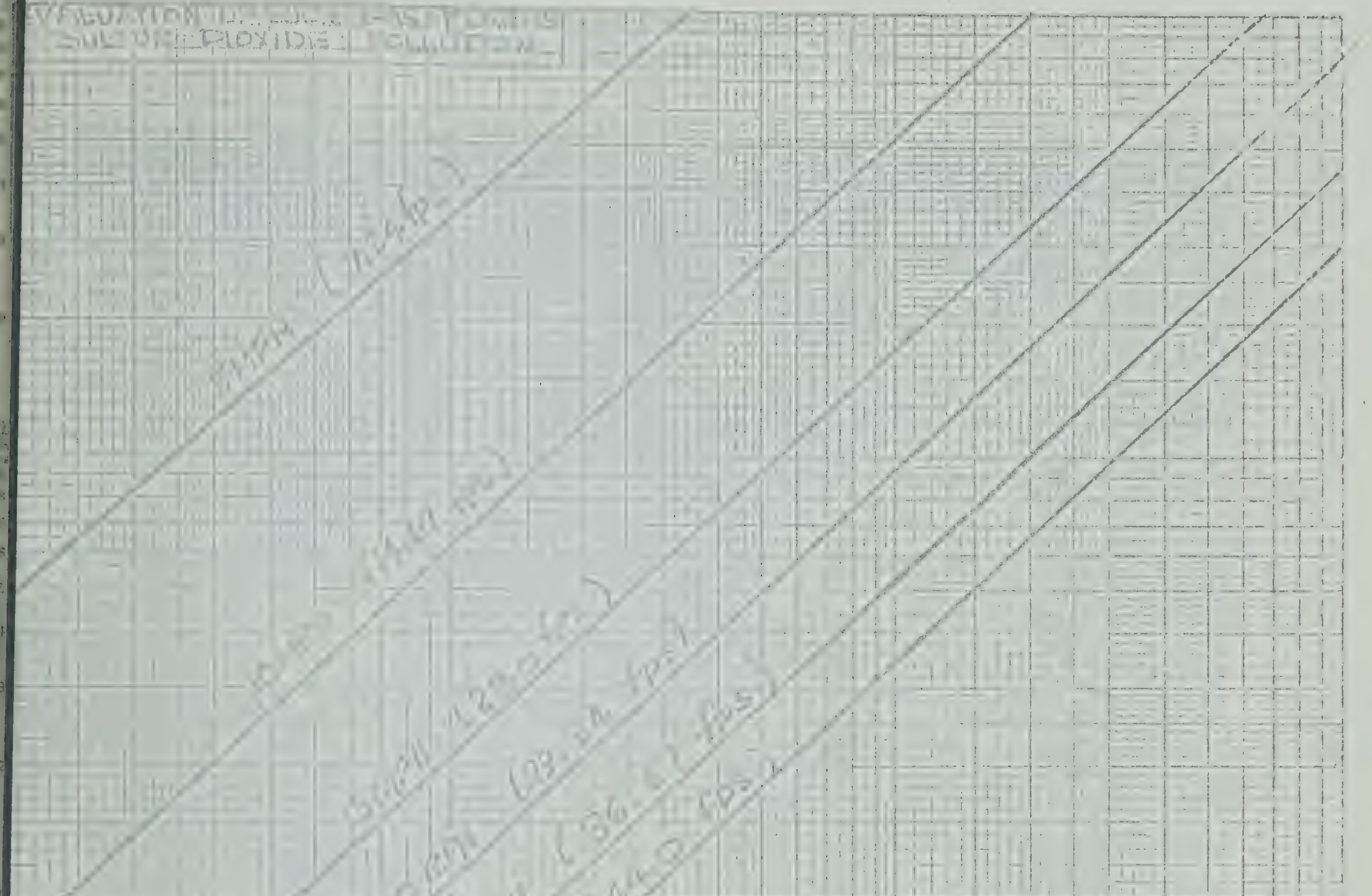
APPENDIX E

EVALUATION OF SOUR GAS FLARES
SULPHUR DIOXIDE POLLUTION

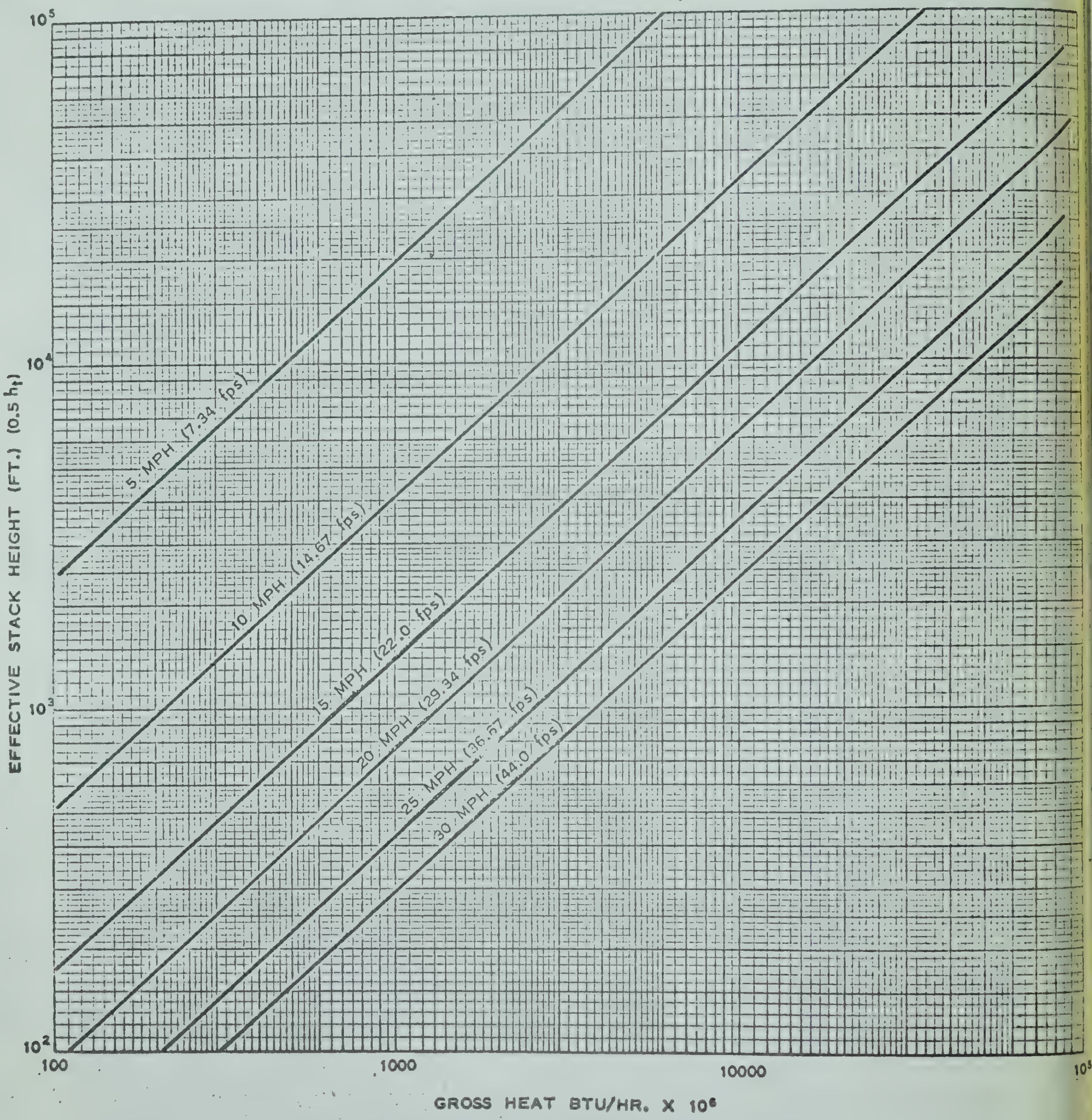


EVALUATION OF SOUR GAS FLARES SULPHUR DIOXIDE POLLUTION
1 PPM DOWN WIND CONCENTRATION




EVALUATION [illegible] SULFUR DIOXIDE POLLUTION
5 MPH (7.33 fps)
10 MPH (14.67 fps)
15 MPH (22.0 fps)
20 MPH (29.34 fps)
25 MPH (36.67 fps)
30 MPH (44.0 fps)
10
100
1000
GROSS HEAT BTU/HR x 10^6

EVALUATION OF SOUR GAS FLARES
SULPHUR DIOXIDE POLLUTION



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INCINERATOR STACK SAMPLING

and

REPORTS

INCINERATOR STACK FLUE GAS SAMPLING

The basic purpose of conducting an incinerator stack flue gas sampling survey is to determine the quantity of pollutant or pollutants being emitted to the atmosphere at that particular time. The conditions of the pollutant emission are also obtained by this survey. As regards the Environmental Health Services Division the results of this type of survey are used mainly to check and see whether or not the particular plant is operating according to the conditions of its Provincial Board of Health Air Pollution Approval but other uses of such a survey are that it can be used by the plant operating personnel to evaluate the plant's sulfur recovery efficiency, to evaluate the need of air pollution control equipment, and to evaluate the progress of an air pollution control program.

The incinerator stack sampling survey may be briefly divided into five separate steps which are as follows:

1) Determining the average velocity of the flue gases at the sampling port location.
2) Determining the average temperature of the flue gases at the sampling port location.
3) Determining the amounts of the principal constituents (O_2, CO, N_2, and CO_2) in the flue gases.
4) Determining the pollutant content of the flue gases.
5) Utilizing the above collected data to calculate the rate of pollutant emission to the atmosphere.

The first step in determining the velocity of the flue gases at the sampling port location and thus the volume rate of flow of the flue gases is the selection of the velocity traverse. For circular flues (the common case) the cross-sectional area is divided into equal areas laid out in concentric circles. Since the concentric circles get narrower as they proceed from the center to the outside of the flue, a special formula is used to locate the test points which are assumed to have the average conditions of the area they represent. The formula used is as follows:

$$Rn = \sqrt{\frac{(n-1)a + a/2}{3.1416}}$$

where Rn = the radius of the n^{th} point from the centre of the circle.
n = n^{th} point from the centre of the circle.
a = total area divided by the number of equal areas.

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If the cross-section at the test location has a fairly uniform flow, that is the range of velocities does not exceed 2 to 1, the minimum number of traverse points is determined as follows:

Cross-sectional Area Square Feet	Number of Test Points
Less than 2	4
2 to 25	12
Greater than 25	20

Where high velocity differentials or extreme turbulence of flow are encountered it may be necessary to double or triple the number of points to establish true conditions.

Once the flue cross-section has been properly arranged into the required number of equal areas the next step is to determine the average velocity of the flue gases at this cross-section. The formula for determining the average velocity of the flue gases at the traverse location is:

$$Vs\ (\text{average}) = 2.9\ Fs \sqrt{\frac{29.92}{Ps} \times \frac{1.00}{G_d} \times Ts} \times \left[\sqrt{H}\right] \text{average}$$

where Vs = average velocity of the flue gas, f.p.s.
Fs = pitot tube correction factor.
Ps = absolute pressure of the flue gas, inches Hg.
Gd = specific gravity of the flue gas referred to dry air at Ts and Ps.
Ts = absolute temperature of the flue gas, °R.
$\left[\sqrt{H}\right]$ ave. = the average square root of the pitot tube draft gauge readings taken over the entire cross-section of the flue, (inches water)$^{\frac{1}{2}}$.

The pertinent data necessary for the average velocity formula are determined as follows:

1. The Pitot tube velocity correction factor, (Fs).

Two types of pitot tubes are generally used:

A. The Standard Pitot Tube (Figure 2):

a) This type plugs rapidly in a moist gas with a high dust concentration and for this reason is limited to gases with low dust loadings.

b) It has a velocity correction factor (Fs) of 0.98 to 1.02 but for all practical purposes it gives differential gauge readings as the true velocity head.

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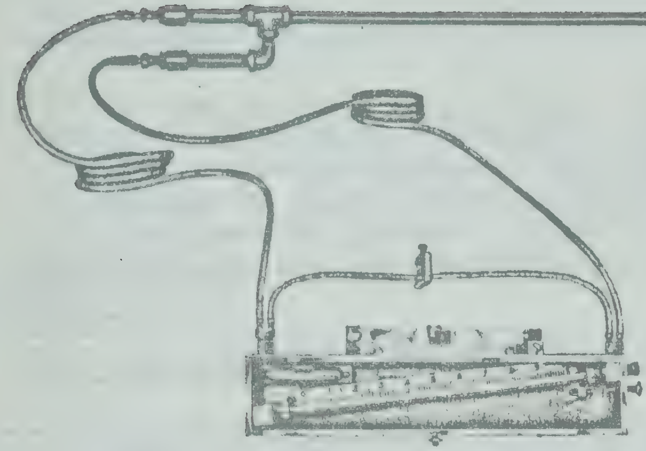
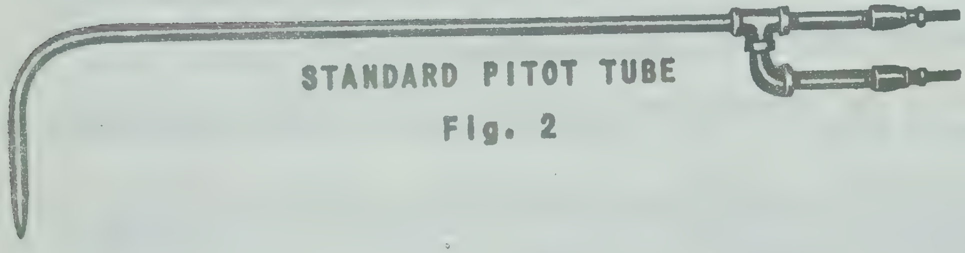


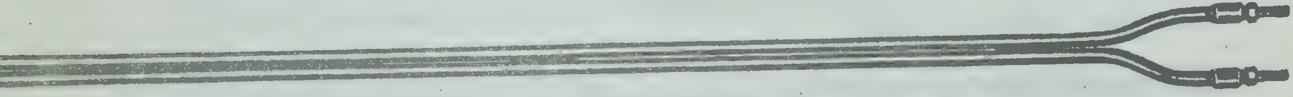
VELOCITY DETERMINATION ASSEMBLY

Fig. 1



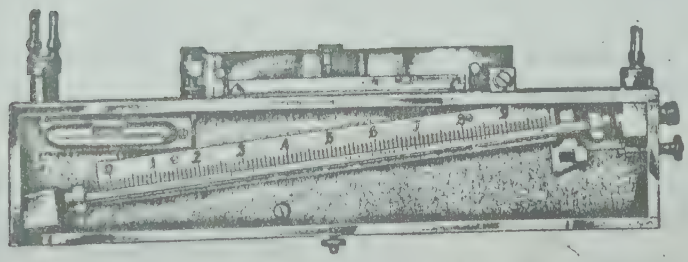
STANDARD PITOT TUBE

Fig. 2



SPECIAL PITOT TUBE

Fig. 3



INCLINED DRAFT GAUGE

Fig. 4

1. The Pitot tube velocity correction factor - Cont'd.

   B. The Type-S Pitot Tube (Figure 3):

      a) This type is used for gases which contain high dust concentrations.

      b) Since it does not give a true static pressure at the point being measured for velocity, a correction factor of 0.83 may be applied to theoretical velocities up to 50 f.p.s. without a great deal of error. However, for very accurate work, the tube should be calibrated over the velocity range of interest.

2. The Differential Draft Gauge Reading at each Traverse Point, (H).

   To indicate the velocity head measured by the pitot tube several types of pressure guages may be used:

   a) Inclined draft gauge (Figures 1 and 4).
   b) U-tube.
   c) Well type manometer.
   d) Pointer type low pressure gauge (Magnehelic).
   e) Hook gauge.

3. The Absolute Temperature of the Flue Gas, (Ts).

   A. To determine the temperature of the flue gas three instruments are commonly used:

      a) The standard mercury thermometer (reading above the maximum temperature of the gas).
      b) The standard base metal pyrometer.
      c) Ratio potentiometer.

      The temperature of the flue gas is obtained by making a temperature profile across the duct in the same manner as the velocity profile. The average of these readings is then used.

   B. To determine the absolute temperature, the following formula is used:

$$Ts = 460 + T$$

where Ts = absolute temperature of the flue gas, °R.
T = average temperature of the flue gas, °F.

4. The Absolute Pressure of the Flue Gas, (Ps).

   A. To determine the pressure of the gas in the flue, two devices may be used:

      a) The flue pressure may be read on the pitot tube differential

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4. The Absolute Pressure of the Flue Gas, (Ps): Cont'd.

A. a) . . draft gauge by connecting the 'static' side of the pitot tube to the gauge, leaving the other end of the gauge open to the atmosphere.

b) If the flue pressure is more than 1-inch of water vacuum, a U-tube should be used. In using a U-tube care should be taken to protect the open end from air currents. Such protection can be provided by placing a loose ball of cotton over the opening.

B. To calculate the absolute pressure in the flue the following formula is used:

$$Ps = \cancel{29.92 + P}\ \text{atmospheric pressure} + P$$

where Ps = absolute pressure in the flue, in. Hg.
P = gauge pressure (vacuum) in the flue, in. Hg.

5. The Specific Gravity of the Flue Gas, (Gd).

A. To calculate the specific gravity of the flue gas:

a) The moisture content of the flue gas, and
b) An analysis of its principal constituents (O_2, CO, N_2, CO_2) on a dry basis must be determined.

B. The moisture content can be determined by:

a) Humidity apparatus with the proper range of thermometers.
b) The amount of condensate collected or the volume increase of the bubbler solutions described in the section headed by 'Flue Sampling Train'.

C. The principal constituents (O_2, CO, N_2, CO_2) can be determined by the use of an:

a) Orsat analyzer, or
b) Fyrite analyzers.

Having determined the average velocity of the flue gases at the traverse location the volume rate of flow of the flue gases at the traverse location is given by:

$$Q = Vs\ (\text{average}) \times As$$

where Q = volume rate of flow of flue gas, c.f.s.
Vs (average) = average velocity of the flue gas at the traverse location, f.p.s.
As = cross-sectional area of the flue at the traverse location, ft.^{2}

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Incinerator Stack Flue Gas Sampling: Cont'd.

The next step in the stack sampling survey is the determination of the pollutant content of the flue gases. This is accomplished by means of a flue sampling train and for stack sampling at gas plants is used mainly for the collection of sulfur dioxide.

A. The Sampling Train consists of:

1) Sampling nozzle and sampling probe.
2) Impingers placed in an ice bath.
3) Silica gel column.
4) Dry gas meter equipped with temperature and pressure gauges on its outlet side.
5) Air pump.

A typical sampling train arrangement is shown in Figure 5. The nozzles and sampling probe should be made of material (stainless steel) not subject to corrosion or damage by high temperatures. The dry gas meter should be protected from outside temperature changes by using insulation, or by placing it in a paper or wooden box. The rubber tubing used to connect the various components of the train should be heavy to avoid collapse due to suction within the train. It is essential that all connections be absolutely tight to prevent outside air being registered by the dry gas meter. A simple test for tightness is to assemble the complete train, tightly block the sampling nozzle, and carefully apply suction until the pressure gauge reaches its maximum. If the meter dial does not creep, the system is tight.

B. Collection of Flue Gas Samples:

1) From the sampling probe a connection is made to four gas washing bottles which are connected in series and placed in an ice water bath. The first and last gas washing bottles are fitted with impingers while the middle two are fitted with a coarse cylindrical frit. The first three gas washing bottles each contain approximately 125 mls. of 5% hydrogen peroxide while the fourth is left dry to trap mist from the preceding three. The ice bath serves to reduce the temperature of the flue gas thus encouraging condensation of water vapor and discouraging evaporation of bubbler solutions.

2) The last gas washing bottle is connected to a silica gel column to reduce the humidity in the gas stream to zero for the protection of the dry gas meter.

3) The silica gel column is connected to the dry test meter followed by the vacuum pump which draws the sample through the sampling train.

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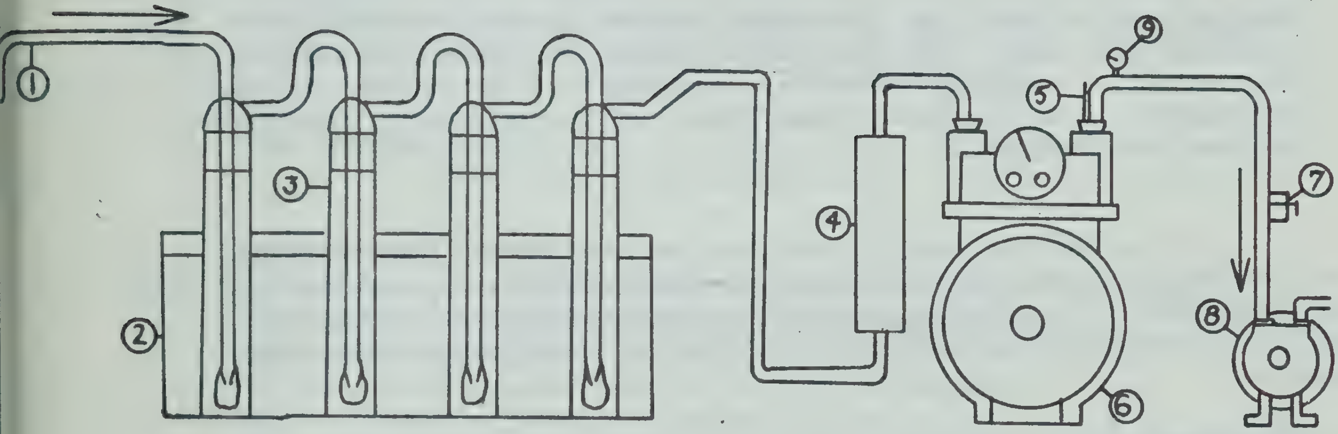
FIGURE 5

Sampling Train for Gaseous Contaminants



1· Sampling probe
2· Ice bath
3· Impingers
4· Silica gel column
5· Thermometer
6· Meter (dry gas)
7· Hose clamp (Valve)
8· Vacuum pump
9· Pressure guage

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B. Collection of Flue Gas Samples: Cont'd.

4) A 1-hour sample is usually withdrawn through the train at a rate of ½ cubic foot per minute for a total of 30 cubic feet. It may be necessary to vary the sampling rate and time depending on the source.

C. Analysis of Flue Gas Samples:

When a sample is completed the H_2O_2 and condensed water solution is measured and recorded and the sample removed to the laboratory for titration with NaOH. The difference between the final and original volumes of the sampling solution is a measure of the volume of water condensate. A more complete description of the laboratory procedure is given in Appendix A.

After the analysis of the flue gas samples all that remains is to calculate amount of pollutant (sulfur dioxide) being emitted to the atmosphere. In addition to the flue gas velocity and volume rate of flow calculations already described the following calculations are required:

A. Water Vapor:

1) The volume of water vapor in the flue gas is calculated from the volume of condensate collected and the residual amount remaining in the saturated air at meter conditions (trapped in silica gel column) by using the following formulae:

$$V_v = 0.00267 \times \frac{V_w \times T_m}{P_b - P_m}$$

where V_v = volume of water vapor (at meter conditions) condensed from the sample and collected in the impingers (ft.^{3}).
V_w = volume of water collected in the impingers (cm.^{3}).
T_m = absolute temperature of the gas at the meter (°R).
P_b = barometric pressure (inches of Hg.).
P_m = gauge pressure (vacuum) of gas at the meter (inches of Hg.).

2) The volume of water vapor trapped in the silica gel column at meter conditions is given by:

$$M_m = \frac{VP \times V_m}{P_b - P_m - VP}$$

where M_m = volume of water vapor (at meter conditions ft.^{3}).
VP = vapor pressure of water at meter conditions (inches of Hg.).
V_m = volume of dry gas registered by the meter (ft.^{3}).
P_b = barometric pressure (inches of Hg.).
P_m = gauge pressure (vacuum) of gas at the meter (inches of Hg.).

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A. Water Vapor: Cont'd.

3) The total volume of water vapor contained in the sample at meter conditions is then given by:

$$M_t = M_m + V_v$$

B. Sulfur Dioxide:

1) The volume of sulfur dioxide collected by absorption in hydrogen peroxide converted to meter conditions is given by:

$$V'_{SO_2} = \frac{A \times N \times T_m \times 2.4 \times 10^{-5}}{P_b - P_m}$$

where V'_{SO_2} = volume of sulfur dioxide sampled (at meter conditions ft.^{3}).
A = volume of standard NaOH solution used (ml.).
N = normality of NaOH solution.
T_m = absolute temperature of the gas at the meter (°R).
P_b = barometric pressure (inches of Hg.).
P_m = gauge pressure (vacuum) of gas at the meter (inches of Hg.).

2) The total volume of flue gases sampled at meter conditions is given by:

$$V_t = V_m + M_t + V'_{SO_2}$$

where V_t = total volume of stack gases sampled at meter conditions (T_m and P_m).
V_m = volume of gas registered by the meter at meter conditions (T_m and P_m).

3) The volume percent of sulfur dioxide in the flue gas sampled is given by:

$$\% \ SO_2 \text{ in flue gas} = \frac{V'_{SO_2} \times 100}{V_t}$$

where V'_{SO_2} = volume of sulfur dioxide sampled (at meter conditions).
V_t = total volume of stack gases sampled at meter conditions (T_m and P_m).

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B. Sulfur Dioxide: Cont'd.

4) The percent moisture in the flue gas is given by:

$$\% \text{ moisture in flue gas} = \frac{M_t \times 100}{V_t}$$

where M_t = total volume of water vapor contained in the sample at meter conditions.
V_t = total volume of stack gases sampled at meter conditions (T_m and P_m).

5) The weight of sulfur discharged to the atmosphere through the incinerator stack is given by:

$$Ws = Q \times \frac{SO_2}{100} \times 86400 \times 3.7728 \times 10^{-5}$$

where Ws = weight of sulfur emitted to atmosphere, long tons per day.
Q = volume rate of flow of flue gas at 60°F & 29.92 inches Hg., cfs.
SO_2 = percentage sulfur dioxide in the flue gas.

INCINERATOR STACK SAMPLING REPORTS

The results of an incinerator stack sampling survey should be incorporated into a report together with pertinent plant operating data for the time of the sampling survey. The Environmental Health Services Division has found it conveneient to summarize all this data in a 'plant operations table' an example of which is included in Table 1. The summary section of the stack sampling report should discuss the pollutant emission rate and the operation of the incinerator stack. If the plant is operating in violation of the Provincial Board of Health Air Pollution Approval then the reasons for this violation and action already taken or to be taken to remedy the situation should be stated.

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	Approval or Design Conditions	SUPPLIED CONDITIONS: Day 1	Day 2	OBSERVED CONDITIONS: Day 1	Day 2
Raw gas inlet rate, MMSCFD.	-	-	-		
Average hydrogen sulfide in raw gas, MMSCFD.	-	-	-		
Average raw gas composition, % H_2S.		-	-		
Raw gas flared, MMSCFD.		-	-		
Acid gas rate to sulfur plant, MMSCFD.		-	-		
Average acid gas composition, % H_2S.		-	-		
Acid gas flared, MMSCFD.		-	-		
Sales gas rate, MMSCFD.		-	-		
Average stack gas temperature, °F.					
Base temperature		-	-		
Midpoint temperature				-	-
Top temperature	-	-	-		
Average volume flow of stack gas @ 70°F & 14.7 psia, CFS.	-			-	-
Average stack gas exit velocity, FPS.	-			-	-
Average stack gas composition, mole %.					
SO_2	-			-	-
CO_2	-			-	-
O_2	-			-	-
N_2	-			-	-
H_2O	-			-	-
Average sulfur to atmosphere, LTD.	-	-	-	-	-
Sulfur production, LTD.		-	-		
Average sulfur in raw gas, LTD.		-	-	-	-
Average sulfur in acid gas, LTD.		-	-	-	-
Average sulfur recovery, raw gas, %.	-	-	-	-	-
Average sulfur recovery, acid gas, %.		-	-	-	-

N.B. - Standard Conditions are 14.7 psia and 60°F.

APPENDIX A

H_2O_2 METHOD OF DETERMINING SO_2 IN A SULFUR PLANT STACK

INTRODUCTION

This method involves bubbling a known volume of the stack gas through a solution of H_2O_2. The SO_2 in the gas is converted to H_2SO_4 which increases the acidity of the sampling solution. The increase in acidity and hence the SO_2 concentration in the stack gas is measured by back-titrating an aliquot of the exposed sampling solution with standard NaOH.

REAGENTS

The concentration of the standard NaOH should be approximately 0.2N. It is prepared by diluting an approximately 1N NaOH stack solution. The exact normality of the NaOH to be used in the titration is determined by titrating against standard .100N H_2SO_4 (available in the lab) to the phenolphthalein end point.

The 5% H_2O_2 sampling solution is prepared by diluting 30% H_2O_2.

Phenolphthalein indicator.

PROCEDURE

Before climbing the stack to make a run, approximately 125 (± .5) ml. of H_2O_2 sampling solution is measured into each of three 250 ml. impingers. The total volume of H_2O_2 used must be recorded. The impingers are placed in an ice-water bath just before the sampling run begins.

After the sampling run has been completed, the impingers are taken into the plant laboratory where the increase in acidity of the sampling solution is measured. There are several steps to be followed in the analysis.

1. Measure the volume of the sampling solution, which now contains an unknown amount of water condensate as well as the acid, with a 100 ml. cylinder. The difference between the final and original volumes of the sampling solution is a measure of the volume of water condensate. Transfer the sample from the impingers into a 1000 ml. volumetric flask. Care must be taken in rinsing the impingers and this rinse water added to the sample in the flask. Dilute with distilled water to 1 liter and mix well.

2. Pipette an aliquot (usually 40 ml.) of the sample into a 250 ml. beaker containing six glass beads.

3. Heat the solution to boiling and boil gently for ten minutes. Allow the sample to cool.

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PROCEDURE: Cont'd.

4. Transfer the sample into a 100 ml. volumetric flask and dilute to the mark. Mix well.

5. Pipette an aliquot (usually 20 ml.) into a 250 ml. beaker, add 50 ml. of distilled water and titrate to the phenolphthalein end point using the standard NaOH.

BLANK DETERMINATION

At least one reagent blank should be run for every plant visited. The sample procedure that was used in analyzing the sample should be followed here, starting with step 2. Step 2 should be altered to read:

> Pipette 15 ml. of fresh H_2O_2 into a 250 ml. beaker containing 6 glass beads and add 25 ml. of distilled water.

The remainder of the procedure is the same.

LAB EQUIPMENT FOR STACK SAMPLING

One 25 ml. burette
Two 20 ml. volumetric pipettes
One 10 ml. volumetric pipette
One 10 ml. graduated pipette
One 5 ml. graduated pipette
Two 100 ml. graduated cylinders
Two 1000 ml. volumetric flasks with rubber stoppers
Three 250 ml. beakers
One 100 ml. volumetric flask with rubber stopper
One bunsen burner with rubber connecting hose
One retort stand
One 4-inch cast iron support ring
One 2-inch cast iron support ring
One burette holder
One 6 x 6 wire gauze square with asbestos center
One magnetic stirrer with mouse
One envelope of glass wool
Two dozen glass beads
One medicine dropper
Stopcock grease
Paper towels
One 65 mm funnel
One 500 ml. Polyethylene wash bottle
One sheet of Kum-Kleen Labels.

SOURCES AND CONTROL OF AIR POLLUTANTS

ASSOCIATED WITH THE SOUR GAS AND OIL INDUSTRY

SOURCES AND CONTROL OF POLLUTANTS ASSOCIATED WITH THE SOUR GAS AND OIL INDUSTRY

I CLASSIFICATION

A. The gaseous pollutants which are associated with the sour gas and oil industry may be separated into two classes:

1. Inorganic Gases.
2. Organic Vapors and Gases.

B. Inorganic gas of significance as air pollutants are:

1. Sulfur Dioxide.
2. Hydrogen Sulfide.

C. Organic vapors or gases of significance as air pollutants are:

1. Hydrocarbons.
2. Mercaptans.

II SOURCES AND CONTROL IN PLANT AREA

A. Major Sources

1. Tail Gas From Sulfur Recovery

a) The major contributor to air pollution from a sulfur plant is the 'tail gas from the sulfur recovery plant'. This gas has a relatively high content of sulfur gases in the form of H_2S, SO_2, COS and CS_2. Other gases such as CO_2, H_2O, N_2 and O_2 would be the main constituents of the effluent.

b) Control Measures

Since SO_2 has a higher odor threshold than H_2S, the tail gases are burnt with fuel gas in an incinerator. In order to ensure relatively complete combustion of the H_2S, the Provincial Board of Health generally requires a minimum stack emission temperature of 1000°F. As the tail gas temperature is 300 - 400°F before incineration, this higher temperature results in a significant increase in the thermal rise. The effluent is emitted to atmosphere through the sulfur plant stack, the height of which had been previously calculated. The height is such that at the approved stack operating conditions, the resulting calculated ground level concentration of SO_2 will meet the minimum requirements of the Provincial Board of Health.

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II SOURCES AND CONTROL IN PLANT AREA

A. Major Sources

2. Flares

a) Although this is not considered to be a continual source, it may become one if a plant upset necessitates flaring of raw gas from the field or acid gas from the sulfur recovery unit/s. Both gases can have a high H_2S content.

b) Control Measures

As in the case of the sulfur plant incinerator, the main purpose of the flare is to burn the H_2S to SO_2. It is therefore most important that all gases reaching the flare tip be ignited immediately and that the flare be equipped with either a non-extinguishable pilot light or/and an automatic ignitor. In order to ensure relatively complete and continuous combustion of all sour streams, the Provincial Board of Health requires that the heat content of any stream prior to entering the flare stack be at least 250 B.T.U./cu. ft. It is also recommended that if sweet fuel is required to meet the minimum heat content requirement, it be added at the base of the flare stack in order to ensure thorough mixing before ignition. Usually a liquid knock-out vessel is installed at the lower portion of the flare so that any liquid in the flare lines would be removed thus lessening the danger of extinguishing the flare.

B. Minor Sources

Although this group of sources can yield low quantities and concentrations of pollutants, they must be dealt with because of the low odor threshold of gases such as H_2S and mercaptans.

1. Spent Caustic

a) Caustic soda may be used to remove trace quantities of H_2S and mercaptans from light petroleum gas. The caustic is regenerated but some waste known as spent caustic remains and must be disposed of.

b) Control Measures

The spent caustic is usually incinerated in a caustic incinerator. Although the main product of combustion is sodium carbonate, there is also SO_2 from the trace sulfur gases. The combustion products are vented either to the main sulfur plant stack or a special stack used mainly for this purpose.

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II SOURCES AND CONTROL IN PLANT AREA

B. Minor Sources

1. Spent Caustic

b) Control Measures: Cont'd.

The spent caustic may also be disposed of by injecting into a disposal well where proper controls will prevent the escape of pollutants. Care must be exercised with these disposal wells in order that water acquifers are not contaminated. Care should also be taken to ensure that when the spent caustic is stored prior to injection, the resulting mercaptan and H_2S emissions do not become a nuisance.

2. Spent Amine

Plants employing an amine process as a means of removing H_2S will have a certain amount of spent amine which, when discarded, will carry over H_2S. The control measures are usually the same as for spent caustic.

3. Burn Pits

a) These sumps generally receive wastes which contain small quantities of H_2S, hydrocarbons, and mercaptans dissolved or free. A good example of such a stream is the salt water from the inlet separators.

b) Control Measures

The best method of controlling emission from the inlet separator salt water or other relatively sour streams is to remove the contaminates before the water is drained to the burn pit. As relatively large quantities of H_2S and hydrocarbons can be dissolved in the water at the high operating pressure of the inlet separator the water should be removed to a surge tank. After the major portion of the H_2S and hydrocarbons have come out of solution, the salt water should be stripped with either sweet gas or steam.

In cases where contaminated streams cannot be treated in the manner outlined, a continually burning flame is placed over the point where the wastes flow into the burn pit. Any combustible gases evolved are burnt immediately to form SO_2, CO_2, and water vapor.

It is advisable that ground level sources of SO_2 be minimized as funneling of the contaminant can result in a high ground level concentration.

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II SOURCES AND CONTROL IN PLANT AREA

B. Minor Sources: Cont'd.

4. Waste Pond

a) Waste ponds generally receive a number of waste streams which for the most part carry very little in the way of pollutants; however, for water pollution control it is necessary to pond these streams rather than run them directly into the watercourses. Some of these waste streams, eg. boiler blow down water, are sent through a settling pond to settle out solids before entering the waste pond. This pond can also receive burn pit overflow. A number of pollutants such as H_2S, SO_2, mercaptans and hydrocarbons may be in this pond.

b) Control Measures

Care should be taken to ensure that any streams which have a relatively high concentration of pollutants are treated before they flow into the waste pond as atmospheric dilution is the only means of controlling the pollutants which evolve from the pond in the form of gases or vapors.

5. Condensate Storage

a) Condensate is stored on the plant site prior to shipment. The main pollutant is generally hydrocarbon vapors due to evaporation losses of the product although if the condensate is not stripped, H_2S or mercaptans may also be present.

b) Control Measures

The Provincial Board of Health requires that either the stored condensates have a true vapor pressure less than or equal to 12 psia or if this condition cannot be met, the firm provide either pressurized storage or vapor recovery. In most cases this requirement is also dictated by economics. In many instances the plant can control the condensate vapor pressure.

6. Pouring of Liquid Sulfur

a) As the liquid sulfur leaves the sulfur recovery plant the major portion is poured onto a sulfur pile. The liquid sulfur solidifies once it has cooled. During the pouring and cooling sulfur vapors and hydrogen sulfide become airborne. The sulfur vapors result from evaporation while the hydrogen sulfide comes out of solution.

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II SOURCES AND CONTROL IN PLANT AREA

B. Minor Sources

6. Pouring of Liquid Sulfur: Cont'd.

b) Control Measures

The sulfur vapor losses are dependent on the speed of the wind. In order to minimize losses, sulfur should be poured during relatively light winds.

Although the quantities or rates of hydrogen sulfide emissions cannot be controlled, the quantities seem to be such that atmospheric dilution is a satisfactory control.

7. Loading of Solid Sulfur

a) Solid sulfur is generally loaded by mechanical shovel into railroad box cars for shipment. The sulfur is taken from the pile, dropped into a device which breaks up the large lumps then either conveyed or dropped into the railroad car. During this operation, sulfur dust becomes airborne.

b) Control Measures

At present, the method of control used by most firms is to load during only relatively light winds. In this way dust emissions are minimized and most of the dust will settle out in the vicinity of the loading operation.

III SOURCES AND CONTROL IN FIELD OPERATIONS

A. Well or Battery Operations

1. Flaring

a) Generally gas field well or batteries do not have a continuous flare. However, well flaring may occur if the well requires treating or testing.

b) Control Measures

In the case of sour gas fields, the required flare stack height is based on the composition of the material to be flared and the expected duration and frequency of flaring. The general requirements are similar to those in Section II, A, 2(b) except that a pilot or automatic ignitor is not required. Generally in such cases flaring is not permitted above wind speeds of 15 mph.

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III SOURCES AND CONTROL IN FIELD OPERATIONS

A. Well or Battery Operations

2. Sour Crude Storage

a) In sour oil field areas, if the crude is relatively sour and it is stored on site, a vapor gathering system may be required. In such a system all of the tank vapors are gathered and sent to a flare.

b) Control Measures

When flaring the vapors from sour crude storage tanks the control measures are similar to those outlined in Section II, A, 2(b), except that a liquid knock out vessel is not required.'

3. Salt Water Storage

In 'wet' gas fields, salt water is removed from the gas at the battery or well site in a separator before the product is piped to the plant. As the separator generally operates at a high pressure, H_2S will be dissolved in the water. When the water is drained from the separator to a storage vessel which is at atmospheric pressure, H_2S will come out of solution.

b) Control Measures

The Department of Health is presently gathering data to determine if the quantities of H_2S evolved justify stringent control requirements.

4. Burn Pits

a) In oil field areas, when lines are pigged or storage vessels are cleaned, the sludge is routed to the burn pit for incineration. The problem is generally an aesthetic one resulting from the smoke emissions.

b) Control Measures

Section 14-3-4 of the 'Provincial Board of Health Regulations for the Control of Air Pollution' specifies the maximum permissible smoke emissions. However, burning should never take place when wind speeds are in excess of 15 mph as the smoke can be funneled along the ground. If conditions for burning are ideal, the smoke should rise straight up and dissipate in the distance. Before burning a large quantity of oil field sludge, an operator should burn a small measurable quantity to check the dispersion.

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IV EMERGENCY OR ACCIDENTAL RELEASES

If any accidental or emergency releases of H_2S occur, the responsible firm is to notify the Provincial Board of Health by telephone within 24 hours of the occurrence and in writing within 72 hours of the occurrence.

FIELD SURVEYS

FIELD SURVEYS

The air pollution survey is necessitated by an actual or potential air pollution problem. There must be a receptor (human, plant, animal or any material) which reacts or could react unfavorably to an air pollutant as well as a source of the pollutant.

I TYPES OF SURVEYS

A. Exploratory

This is the most precise type of survey in that continuous pollutant readings are taken from a mobile laboratory and/or a temporary monitoring station which is located in the vicinity of the sour gas plant or in the sour oil field. The mobile unit or station is generally located at a site for a period of two to three weeks. The area to be sampled during any given period is generally selected on a random bases. The only general rule followed is that the sampling period for any one area be altered between summer and winter periods. The selection of the actual sampling site involves consideration of matters which will be covered in a later section.

The only time the sampling area is not chosen randomly is if a justifiable complaint is received. Such a complaint is generally the result of a local citizen or group of citizens claiming vegetation damage, eye or nose irritation, ailing livestock or a variety of other affects of an aesthetic, economic, health or nuisance nature which they feel are caused by air pollution.

Upon receipt of the initial complaint one or several members of the Air Pollution Control Section generally conduct interviews in the area of the complaint. If the findings indicate that the complainant had reason to complain and the level of pollutants in the atmosphere may be the cause of the complaints, then an exploratory air monitoring survey would be in order.

At the present time it is felt that the following ground level concentrations of SO_2 are the maximum which are acceptable:

8 hour average - 0.3 ppm
1 hour average - 1.0 ppm
3 minute average - 1.5 ppm

The monitoring survey lasting from several weeks to over a year may involve one or both of the mobile laboratories as well as one or more temporary monitoring stations.

B. Exposure Cylinder

This type of survey is conducted by the Department of Health and the gas plant or field operators in the vicinity of all sour gas plants or oil fields. It is a continuous type of survey in that the hydrogen

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I Types of Surveys

B. Exposure Cylinder: Cont'd.

sulfide and total sulfation cylinders report what would be considered a monthly average pollution figure as they are exposed for approximately a one month period (weather permitting) before they are replaced. This type of survey provides the Department with a invaluable source of information as it is a rough indication of the trends in any given area.

In the case of sour gas plants the Department attempts to set up the exposure stations before the plant goes on stream. In this way the increase in pollution over the previous ambient level can be determined. It is important to note that when the exposure cylinder values are studied in order to determine the pollution trends, only two types of valid comparisons can be made. Either each station is considered on its own or the yearly averages of all stations in the area are compared. As each area has its own unique meteorological conditions and sources and each cylinder is located in its own unique topography, the reported values are also unique. It must also be remembered that there is a general seasonal variance with the values being highest in the winter and lowest during the summer.

There is no maximum allowable concentration as such for the total sulfation or hydrogen sulfide cylinders, although most of the reported values from the total sulfation cylinders are less than 0.3 SO_3 equivalent mg./day/100 sq. cm. and for the hydrogen sulfide cylinders are less than 0.05 SO_3 equivalent mg./day/100 sq. cm. The readings in any given month are considered to be significant when they deviate from what is considered to be the norm of the station for the time considered. Tables I-A and I-B summarize some average readings which have been obtained in a few cities in Canada and Great Britain.

As the total sulfation cylinders also react with H_2S, it is advisable for the sake of comparing the total sulfation and hydrogen sulfide cylinder results, to report both results in the same units. The most common units are SO_3 equivalent mg./day/100 sq. cm.

There is no relationship between units of SO_3 equivalent and parts per million (ppm). Although various studies have been made it is impossible to relate these two unless the concentration of sulfur compounds is constant throughout the exposure period. This can be accomplished in the laboratory but it never occurs as an actual situation. As an example, a cylinder exposed to a low SO_2 concentration for one month can have the same final reading as a cylinder which is exposed to a relatively high concentration for five days.

The exposure cylinder survey was developed in 1932 at the Building Research Station in England. Details of the original instrument and developmental investigations are described in a booklet titled 'The Investigation of Atmospheric Pollution', Fuel Research Station, 1948.

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TABLE I-A

TOTAL SULFATION as SO_3 Equivalent in mg./day/dm.^{2}

Date		Ottawa	Montreal	Halifax		Vancouver
				Dalhousie	Fisheries	B.C.
1958	Jan.	0.71	2.47	1.35	1.35	-
	Feb.	0.60	2.33	1.08	3.35	0.94
	March	0.60	2.37	0.89	2.38	1.23
	April	0.52	1.79	0.94	2.67	-
	May	0.47	1.28	0.54	2.17	0.63
	June	0.31	0.98	0.27	1.05	0.49
	July	0.27	0.75	0.17	0.84	0.57
	Aug.	0.31	0.91	0.19	0.90	0.61
	Sept.	0.36	0.99	0.49	1.48	0.97
	Oct.	0.42	1.24	0.73	1.83	0.88
	Nov.	0.65	2.01	0.49	2.66	-
	Dec.	0.83	3.18	1.03	4.47	-
1959	Jan.	1.13	2.78	0.95	4.84	-
	Feb.	0.69	2.81	0.67	3.33	
	Mar.	1.02	2.54	0.80	3.92	
	April	0.66	1.82	1.06	3.23	
	May	0.45	1.26	0.52	2.47	
	June	0.44	1.10	0.33	1.13	
	July	0.30	0.80	0.10	0.67	
	Aug.	0.30	0.98	0.26	0.86	
	Sept.	0.29	1.04	0.20	0.94	
	Oct.	0.43	1.37	0.48	1.87	
	Nov.	0.68	1.69	0.94	2.09	
	Dec.	0.77	2.26	1.23	2.92	
1960	Jan.	0.80	2.77	0.91	2.04	
	Feb.	0.48	2.61	1.15	2.39	
	March	0.47	2.57	0.81	1.90	
	April	0.43	1.88	0.63	1.97	
	May	0.26	1.00	0.68	1.35	
	June	0.30	0.71	0.15	0.81	
	July	0.32	0.74	0.11	0.60	
	Aug.	0.25	0.85	0.14	0.51	
	Sept.	0.23	0.82	0.30	0.76	
	Oct.	0.49	1.54	0.39	1.80	
	Nov.	0.60	1.40	0.63	1.79	
	Dec.	0.59	1.55	0.27	1.95	

TABLE I-B

URBAN SITES IN GREAT BRITAIN (Data from Dept. of Scientific and Industrial Research

City	Year	mg. SO_3/dm.^{2}/day Summer	Winter
Cardiff City Hall	1940-1941	0.62	1.52
	1941-1942	0.75	1.77
	1942-1943	0.67	1.48
	1943-1944	0.68	1.59
Dublin	1940-1941	0.86	2.05
	1941-1942	0.58	1.17
	1942-1943	0.49	0.80
Glasgow	1941-1942	-	2.15
	1942-1943	1.52	1.79
	1943-1944	-	2.43
Leeds	1939-1940	1.60	3.95
	1940-1941	1.62	3.80
	1941-1942	2.22	5.17
	1942-1943	2.67	5.62
London (County Hall)	1939-1940	1.96	4.29
	1940-1941	1.55	5.63
	1941-1942	2.37	5.45
	1942-1943	1.97	4.66
	1943-1944	2.46	4.75
Manchester	1939-1940	1.05	2.40
	1940-1941	1.18	2.87
	1941-1942	1.18	3.05
	1942-1943	1.15	2.48
	1943-1944	0.95	3.24

I Types of Surveys

B. Exposure Cylinder: Cont'd.

This type of survey is carried out by exposing strips of lead dioxide and zinc acetate to the atmosphere for a known period of time, generally one month. Sulfur dioxide and other sulfur compounds react with PbO_2 to form $PbSO_4$ while hydrogen sulfide reacts with $Zn\ (C_2H_3O_2)_2$ to form ZnS. The chemical procedures are discussed in the appendix section of this manual.

The following facts have been established concerning the reaction between lead peroxide and sulfur dioxide.[1]

1. Both the reagent (lead peroxide) and the products (lead sulphate) are insoluble in water.
2. The yield of lead sulfate is proportional to the concentration of sulfur dioxide for all concentrations up to one part per thousand.
3. When air containing a constant proportion of sulfur dioxide is blown slowly past a test surface of lead peroxide, the reaction goes at a constant rate until more than 15% of the lead peroxide has been converted. In this case the resulting reading is approximately 13 mg. $SO_3/100\ cm.^2/day$.[2]
4. The reactivity is not significantly dependent on wind speed under the following test conditions:

Conc. of SO_2 (ppm)	Wind Speed (mph)
30-700	.067 - .67
1 - 6	3.3 - 20.1
< 1	.33 - 17.9

5. The reactivity increases 1% for a temperature increase of 12.5°F.
6. There is no significant correlation with relative humidity.
7. The reactivity increases when the lead peroxide surface is wet.
8. Different batches of lead peroxide can have different reactivity.

Although no article discussing the reaction of hydrogen sulfide and zinc acetate could be located, the following facts were found concerning the reaction of lead acetate and hydrogen sulfide.[3] As both chemicals are used for H_2S detections it is felt that the following general statements may be true for each reaction:

1. The reaction rate increases significantly with increased air turbulence.

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I Types of Surveys

B. Exposure Cylinder: Cont'd.

2. Variations in relative humidity between 57% and 97% have no affect on the rate of reaction.

3. Methyl mercaptan, dimethyl sulfide and dimethyl disulfide in concentrations much higher than normally present in the outdoor atmosphere, had no significant effect on the rate of reaction.

C. Research

Sulfur in Vegetation

In many cases, one of the first indication that an area has an air pollution problem is the injury or damage to plant or animal life.

Sulfur dioxide is the most widespread pollutant in the vicinity of sour gas plants or oil fields and can cause acute or chronic plant damage. Chronic plant injury shows up as areas of limited cell injury while acute plant injury results in total tissue collapse. The degree of plant injury caused by this pollutant follows a direct time-concentration relationship with a definite threshold. It appears that plants can tolerate a continual exposure below a threshold of about 0.2 parts per million without injury. It is thought that the cells in the leaf can in some manner detoxify such small concentrations by converting the sulfur dioxide into less harmful substances. However, if the threshold limit is exceeded, then the higher the sulfur dioxide concentrations the less time required for plant injury to result.

Samples of first and second year coniferous needles and deciduous tree leaves are collected in plastic bags and stored in a deep freeze until the sulfur content is analyzed. The sulfur content as a percent of total dry weight of the needles or leaves is determined following the Official Methods of Analysis of the Association of Official Agricultural Chemists (1955). In order to include most of the growing season, samples are collected in the latter part of August, September or October.

References:

[1] 'Measurement of Sulfur Dioxide with the Lead Peroxide Instrument', Department of Scientific and Industrial Research, 1948.

[2] 'The Measurement of Sulphur Dioxide and Chlorides in the Atmosphere at Canadian Exposure Sites' - Foran, Wellington and Gibbons, C M & S, 1958.

[3] E. F. Galardi and R. M. Manganelli, Laboratory Study of Lead Acetate Tile Method for the Quantitative Measurement at Low Concentrations of Hydrogen Sulfide' - Journal of Air Pollution Control Assoc. 13:305-309 (1963).

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II MONITORING EQUIPMENT

A. Mobile Units

The Department presently has two mobile monitoring laboratories which are used to monitor the atmosphere in the vicinity of gas plants and oilfield areas. The following equipment is used in Unit No. 1:

1. A Davis Instruments Company electroconductivity analyzer Model No. 70A1 for measurement of SO_2. It can be operated in ranges of 0-5 ppm and 0-50 ppm and has a lower limit of 0.005 ppm. A pyrolyzing furnace can be connected if requirements call for measuring total sulfur compounds.
2. A Research Appliance Co. A.I.S.I. automatic spot tape H_2S sampler.
3. An anemograph MSC Type B c/w anemograph clock and drum assembly for indication of wind speed and direction. This equipment was purchased from the Department of Transport.
4. A Science Associates Inc. Model No. 351 recording electric barograph for recording of barometric pressures.
5. A Hughes Owen Co. Ltd. Model No. 8169 recorder hair hygrothermograph for recording of temperature and relative humidity.

The equipment is the second unit is the same except for the following:

1. The Davis Instruments Company unit is a Model 11-7010 RDF.
2. The Beckman and Whitley Inc. Model K103A High Resolution Type F Wind system is used instead of Department of Transport equipment.

Please note that the equipment listed above is for the sake of general information and does not constitute endorsement by this Department.

III SELECTION OF SAMPLING SITE

The choice of the actual sampling site/s will vary with the type of survey to be conducted.

For an exposure cylinder or vegetation survey, the only limitations on sampling sites are that they must be accessible and in the zone of pollution (generally ½ to 4 miles radius from a single point source depending on the quantity of SO_2 emitted). As both surveys are for the purpose of indicating general pollution trends in all directions from the source, the entire area surrounding a sour gas plant or the sour oil or gas field areas themselves would be spotted with sampling sites. There may be a higher concentration of

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III SELECTION OF SAMPLING SITE: Cont'd.

sampling sites downwind from the most predominant wind, or in a valley if it tended to funnel the winds.

Site selection for a routine exploratory survey is much more involved. As the temporary station or mobile unit will generally be at a location for only a relatively short period of time, it is most important that the selected site be such that the units be in an area where the most information can be obtained.

In selecting a site, some factors to be considered are:

1. Wind Direction:

   The site must be such that the prevailing wind direction is from the source to the sampling site. As the prevailing winds vary with area and season this is a most important consideration.

2. Zone of Pollution:

   The formulae used in the usual calculation have all been developed in England and the United States. While they represent a good estimation of actual conditions they be no means provide an absolute answer. These equations indicate that the maximum ground level concentration from an elevated source generally occurs from ten to twenty effective stack heights downwind. However if there is a ground level source, the maximum ground-level concentration would occur closer to the source.

3. Influence of Topography:

   There are equations which make allowance for uneven terrain when calculating the resulting ground level concentrations thereby enabling an estimate of the resulting ground level concentration. In areas where the general terrain is hilly or mountainous, these equations are used. The sites where the resulting ground level concentration should be highest can be estimated from these equations.

4. Exposure Cylinders:

   The results from the exposure cylinder surveys can be used to determine the area where the average total sulfation or hydrogen sulfide concentration is the highest. As the cylinder values are affected by all of the forementioned points they are a useful tool for site selection. However, if one intends to determine the affect of only a single source (eg. sulfur plant stack), care must be taken that the cylinder values used for site determination are not being affected by other sources (eg. battery flare).

5. Site Access:

   A sampling site should be easily accessible since it must be visited at regular intervals.

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III SELECTION OF SAMPLING SITE: Cont'd.

6. Availability of Electricity:

As most of the analytical equipment requires 110 volt power, the site must be serviced by electricity. Portable generators are available but should be used only as a last resort.

IV PRESENTATION OF DATA

Once an air pollution survey has begun, there is a large quantity of data which must be tabulated and summarized. The aim of the tabulations and summarization is to present the data in a form from which conclusions can be drawn. If the data is not presented in a form which enables the extraction of the maximum amount of information, it is not being used to its full capacity and is not serving the purpose of the survey. In the ensuing subsections, only the manner in which the Department reads and summarizes some of the pollution data will be presented.

A. Exploratory Surveys

1. Sulfur Dioxide Data

A peak and an average reading are read from each recording on the strip chart. In addition to this, the date of the recording and the start and end time are noted.

The method of peak reading is generally by the method of setting readings into triangles. Therefore, the peak reading is the value of the height of the triangle and the average is $\frac{1}{2}$ the value of the peak. If the reading takes the form of a rectangle the peak and averages are the same.

The data is punched on computer punch cards and once the mobile unit has left the site or accumulated sufficient data to warrant analysis, all data is processed by computer.

The computer program summarizes the average sulfur dioxide readings by calculating the cumulative times of occurrence in each of the following ranges and then calculating a frequency distribution table:

SO_2 ppm	
0.0000	
0.0001	0.0049
0.0050	0.0089
0.0090	0.0099
0.0100	0.0199
0.0200	0.0299
0.0300	0.0499
0.0500	0.0799
0.0800	0.0999
0.1000	0.1499
0.5000	0.9999
1.0000	9.9950

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IV PRESENTATION OF DATA

A. Exploratory Surveys

1. Sulfur Dioxide Data

If the average reading is greater than .04990 ppm, information concerning the day of the reading, time and duration of reading, the peak and average reading, and wind information at the time of the reading are printed.

All readings are correlated with winds in two distinct forms. In the first instance, the minutes of readings with each wind direction are tabulated and the percentage of the total readings which each wind accounted for is calculated. In the second instance, the number of hours of wind from each direction while the sampling instrument was operated is calculated and divided into the number of hours of readings from each wind direction. The resulting figure is the fraction of the winds from each direction which resulted in readings.

In Alberta most peak SO_2 readings are in the 0 - 1 ppm range. There have been a few readings in the 1 - 10 ppm range and a very occasional reading in excess of 10 ppm.

2. Hydrogen Sulfide Data

The H_2S data is treated in a manner similar to the SO_2 data. As the spot tape sampler is generally run on a three hour cycle, the readings obtained are an average reading for the period. Concentrations observed in Alberta have ranged from zero to a level which caused entire tapes to blacken.

3. Total Sulfation Data

If the readings indicate that significant quantities of H_2S are present, the SO_2 analyzer can be equipped with a pyrolyzing furnace which burns all oxidizable sulfur compounds to SO_2. The reported readings are total sulfur compounds (total sulfation).

These readings are generally summarized in a manner similar to that noted for SO_2 and H_2S.

B. Exposure Cylinder Data

The exposure cylinders are exposed for approximately a one month period. When sufficient back data is available yearly and seasonal averages are calculated for each station and area average are calculated on a monthly, seasonal and yearly bases.

The seasons are composed of the following months:

Spring: March, April, May
Summer: June, July, August
Fall: September, October, November
Winter: December, January, February

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IV PRESENTATION OF DATA

B. Exposure Cylinder Data

As it is difficult to detect trends from raw monthly data, the Department has found it advantageous to plot the cylinder results. At the present time plots of the monthly values and yearly averages are made for each station.

C. Vegetation Surveys

The data is received once per year. The values in each area are averaged and the yearly averages are plotted.

PLANT OPERATING DATA

PLANT OPERATING DATA

The sulfur recovery plants and sour gas plants which have a Final Air Pollution Approval are required to submit to the Environmental Health Services Division a summary of their monthly operating data and monthly exposure cylinder results before the end of the month following the month for which the data applies. The operating information generally required includes the following daily averages, totals or minimums:

1. Raw gas inlet rate (total).
2. Percent H_2S in the raw gas (average).
3. Condensate production (total).
4. Average Reid vapor pressure of the condensate.
5. Sulfur production (total).
6. Sulfur or sulfur dioxide emission (total).
7. Volume of gas flared (total for each source).
8. Percent H_2S in the flared gas (average for each source).
9. Fuel gas added to flared gas (total for each source).
10. Stack emission temperature (minimum).

When the data is received, the daily sulfur emission rate is calculated according to the following general equation:

$$\underset{\text{LTS}}{\text{Sulfur emission rate}} = (\underset{\text{MMSCFD}}{\text{Raw gas inlet}} \times \%\ H_2S \times \text{conversion factor}) - \underset{\text{LTS}}{\text{production}}$$

The conversion factor is calculated as follows:

$$\frac{32.066\ \text{lb. S}}{\text{lb. mole } H_2S} \times \frac{1}{\frac{379.43\ \text{ft.}^3\ H_2S}{\text{lb. mole } H_2S}} \times \frac{\text{LTS}}{2240\ \text{lbs. S}} = 3.7728 \times 10^{-5}\ \frac{\text{LTS}}{\text{ft.}^3\ H_2S}$$

The ideal gas law is used to adjust the conversion factor to the applicable raw gas inlet conditions.

From the submitted monthly operating data, the Division plots the following information on running monthly - yearly graph paper; Note that any figures involving a 'Percent of Time' are calculated by dividing the number of days the condition was not met by the total number of operating days:

1. Average sulfur dioxide or sulfur emission rate:
    a) Submitted emission rate
    b) Rate calculated by Division
2. Percent of time emission limit exceeded:
    a) Submitted emission rate
    b) Rate calculated by Division
3. Percent of time emission temperature was even momentarily below approval minimum.
4. Average of the minimum emission temperatures.

APPENDIX A

LEAD DIOXIDE EXPOSURE METHOD FOR THE DETERMINATION OF TOTAL SULFATION

In exposure tests for the determination of mean values of total sulfation pollution in the atmosphere the following steps are carried out:

1) Strips of surgical gauze two feet long and two inches wide are wrapped around 8 oz. Armstrong jars and secured to the jars with cotton thread.

2) The lead dioxide paste is prepared by mixing approximately 100 gm. of PbO_2 powder with a solution of gum tragacanthin. The solution of gum tragacanthin is prepared by mixing 3 gm. of gum tragacanthin with 15 mls. methanol and diluted to 300 mls. with distilled water. This gum soltuion is added to and mixed with the PbO_2 powder until a consistency is reached that affords easy spreading of the PbO_2 paste on the surgical gauze with a small brush. If approximately 100 gm. PbO_2 are used to make the paste of the desired consistency, there should be enough paste to cover 10 strips of surgical gauze.

GRAVIMETRIC ANALYSIS FOR TOTAL SULFATION FROM EXPOSURE CYLINDERS

The gauze strip from the jar is removed and placed in a 600 ml. beaker after the exposed surface area has been measured. Care must be exercised in removing the gauze strip and transferring it to the 600 ml. beaker or some of the PbO_4 may come off in this process. Add 5 gm. of Na_2CO_3 to each sample followed by 100 ml. of distilled water. The mixture is stirred and allowed to stand for at least three hours, and then heated at 80°C for between 30 and 45 minutes, without letting the volume to go below 80 ml. The mixture is then filtered with Watman No. 12, 18.5 cm. folded filter paper doing an adequate job. Wash the contents of the filter paper several times with hot distilled water and acidify with 1:1 HCl using methyl orange as an indicator and while stirring add about 20 ml. of warm 10% $BaCl_2$ solution. The precipitate is digested at 80 - 90°C for at least two hours and then filtered through Watman No. 40 ashless filter paper. After the precipitate is washed with small portions of hot water to make the washings chlorine free, the filter paper and precipitate are placed in weighed crucibles that have been pre-ignited at 800°C for at least 3 minutes. The filter paper is charred by the use of a bunsen burner and ignited for not less than thirty minutes at 800°C in a muffle furnace. Cool the crucibles and weigh to determine the weight of the precipitate.

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CALCULATION

$$SO_3 \text{ equivalent mg./day/100 sq. cm.} = \frac{\text{mg. of } BaSO_4 \text{ ppt}^{d} \times \frac{80.06 \times 100.0}{233.42}}{\text{days x area}}$$

In the above formula

'days' represents the number of days that the cylinder was exposed.

'area' represents the exposed surface area of the gauze strip.

'$\frac{80.06}{233.42}$' represents mg. of SO_3 in the right hand side of the equation.

'$\frac{100}{\text{Area}}$' represents the 'per 100 sq. cm.' in the right hand side of the equation.

'80.06' represents equivalent weight of SO_3.

'233.42' represents equivalent weight of $BaSO_4$.

ZINC ACETATE EXPOSURE METHOD FOR THE DETERMINATION OF HYDROGEN SULFIDE

In the exposure tests for the determination of the mean value of hydrogen sulfide pollution in the atmosphere, two inch wide strips of Watman No. 2 filter paper are impregnated with a solution containing 5% zinc acetate and 5% glycerine. The filter paper is soaked for fifteen to twenty hours in the acetate solution and then removed and allowed to dry until the filter paper strips are just slightly damp. The tapes are then secured to the jars with cotton thread.

VOLUMETRIC ANALYSIS OF HYDROGEN SULFIDE FROM EXPOSURE CYLINDERS

The exposed surface area of the paper is measured before it is removed from the jar. After the paper is removed it is folded to fit into the bottom of a 600 ml. beaker. 150 ml. of distilled water is added thoroughly immersing the filter paper, then 10 ml. of 0.025 N iodine followed by 5 ml. of concentrated HCl. If, after stirring the brown color of the solution fades out, 10 ml. portions of iodine are immediately added until the brown color remains and record the total amount. The solution is back titrated with 0.025N sodium thiosulfate adding ½ ml. of starch solution near the end point. The end point is blue to clear to pink. The titration volumes should be read and recorded to the nearest 1/10 ml. An iodine determination should be made on the blank.

All volumes of iodine are converted to equivalent volumes of $Na_2S_2O_3$, eg. if 9.7 ml. of 0.025N $Na_2S_2O_3$ are found to equal 10 ml. of iodine (9.7/10 and if 20 ml. of iodine were used initially, this would be recorded as (20 x 9.7/10) 19.4 ml. of $Na_2S_2O_3$.

Standardization of 0.025N Sodium Thiosulfate

Measure 10 ml. of 0.1N potassium dichromate solution into a 400 ml. beaker containing 25 ml. H_2O, 5 ml. concentrated HCl and 1½ gm. KI. Allow the reaction to proceed in the dark for 5 minutes, then dilute to 500 ml. and titrate with 0.1N $Na_2S_2O_3$ adding ½ ml. starch solution near the end point. The end point changes from opaque blue to a transparent pale green.

$$\text{Normality of } Na_2S_2O_3 = \frac{(\text{ml. of potassium dichromate}) \times (\text{normality of potassium dichromate})}{\text{ml. of } Na_2S_2O_3}$$

CALCULATIONS:

$$1.\ \text{mg. of } SO_3/100 \text{ sq. cm.} = \frac{\text{ml.} \times N \times 40.03 \times 100}{\text{area in sq. cm.}}$$

In the equation

'ml.' represents the number of mls. of iodine that reacted with the sulfite in the sample expressed in terms of ml. of 0.025N $Na_2S_2O_3$. For example, if in running the iodine blank you find

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CALCULATIONS: Cont'd.

'ml.' . . that 9.7 ml. of 0.025N $Na_2S_2O_3$ are equivalent to 10 ml. of the iodine which was added to each sample. If after adding 10 ml. of iodine to the sample it is found that it takes 4.7 ml. of 0.025N $Na_2S_2O_3$ to back titrate the excess iodine so in this case the sample contained the sulfide equivalent to (9.7 - 4.7) or 5.0 ml. of 0.025N $Na_2S_2O_3$ and in this case the 'ml.' would be 5.0

'N' represents the normality of the $Na_2S_2O_3$.

'40.03' represents the equivalent weight of SO_3.

'ml. x N x 40.03' represents the 'mg. of SO_3' in the right hand side of the equation.

2. Corrected mg. of SO_3 /100 sq. cm. = mg. of SO_3/100 sq. cm. (of sample).

− mg. of SO_3/100 sq. cm. (of blank).

3. mg. of SO_3/day/100 sq. cm = $\frac{\text{corrected mg. of } SO_3\text{/100 sq. cm.}}{\text{no. of days sample was exposed.}}$

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